Fermi National Accelerator Laboratory

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Fermilab Research Results 1978-1988

Editors:
Daniel R. Green and Leon M. Lederman
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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1 Introduction

Fermilab concluded its second decade as a research center in High Energy Physics in December 1988. This was an important period for the field in many respects, witnessing the culminating discoveries at CERN of the $W^{\pm}$ and Z^0 bosons, the mediators of the weak interactions, with properties as predicted almost fifteen years earlier by the the standard gauge theory of electroweak interactions.

The first ten years witnessed Fermilab playing a major role in the mapping out of the Standard Model of the elementary particles and the structure and nature of their interactions. The world's highest energy synchrotron, designed for 200 GeV and operated at 400 GeV, was created. Of paramount importance was the discovery of the Υ at Fermilab, which, together with the τ at SLAC, established the existence of a third generation of quarks and leptons. Some of the earliest observations of the neutral current interactions occurred at Fermilab in this period, and its detailed properties were surveyed. Early muon scattering experiments gave structure functions, but also provided the first evidence of scaling violations, an essential prediction of QCD. Dilepton studies gave the first structure functions for pions and this would later lead to observations of subtle higher–order QCD effects in the quark–antiquark system. Today Fermilab stands poised to complete the periodic table of the elementary particles with a search for the top–quark in CDF — or, perhaps to go beyond, should nature deploy yet a fourth generation within the reach of the Tevatron or a future Tevatron Upgrade.

It will be clear to any reader of this document that Fermilab and its users continued in the ten years of 1978 to the present to play *an essential role* in the mapping out of the fundamental new principles and the broadening of the detailed knowledge base of the special properties of matter and interactions at energy scales up to $\sim$ 100 GeV. The highlights of these accomplishments will be briefly reviewed here. We will also discuss the Tevatron and CDF which have been fully commissioned and are now operating and producing physics results which will be reported in the future.

1.1 Theoretical Preamble

As it appears now, all known interactions are described by the principle of "local gauge invariance." This principle is now as firmly rooted in theoretical physics as are Special Relativity and Quantum Mechanics, the great achievements of two earlier generations. It suggests that an ultimate unification of all interactions at some high energy scale probably occurs which dictates all of our observed patterns of quarks, leptons and gauge bosons, and no doubt implies additional interesting physics at intermediate scales between our "low energy" world and the ultimate scale of unification. All of this has fundamental implications for the nature of the origin and very early evolution of our Universe.

Theorists applied and extended this principle throughout the past decade primarily in the construction of string theories, which in some sense are systems with the "most gauge invariance" ever contemplated. These provide a rigorous mathematical setting for the unification of all interactions, including Einsteinian gravity, which had previously resisted incorporation into unification schemes. Astrophysicists supplied constraints and used these ideas to further complete and extend the standard cosmology, a kind of "Bayeux Tapestry" of our cosmic heritage. In spite of these miraculous theoretical advances, fundamental new, and old, theoretical questions still abound. For example, we still haven't a hint of understanding the origins and patterns of quark and lepton masses and mixing angles. Any bold conceptual leap hinges crucially upon the elucidation of the physics at 1000 GeV. Here an understanding of the nature of the breaking mechanism of the electroweak symmetry should emerge, and with it perhaps yet another layer of new dynamics will be revealed. The result of that understanding can only serve to modify and stimulate the quest for the ultimate "theory of everything" in a fundamental way.

Explication of the breaking mechanism of the electroweak symmetry is the objective of the future SSC. SSC construction has now been proposed by the President in his FY 1990 budget and the Department of Energy has announced the preferred site. However, SSC is about ten years away from commissioning and producing any new physics. It is clearly the province of such institutions as Fermilab to bridge the gap between now and then. In fact, Fermilab can be the leading physics facility in this interim period, enjoying a machine of the highest energy ever achieved, upgradable to higher luminosities and energies and detector sensitivites. It is conceivable that at Fermilab indications of the expected new structure at ~ 1000 GeV will be seen with the Tevatron and Tevatron Upgrade. Indeed, the "Periodic Table of Quarks and Leptons" is missing at least one obvious entry — the top quark. The race between CERN and Fermilab is now on to find it and it should be known if the top quark is less massive than 100 GeV very soon.

We thus stand at a cross–roads in physics, at the end of the very dramatic period of the development and confirmation of the Standard Model, while waiting to see the new physics essential to the breaking mechanism of electroweak phenomena in the future. The previous decade was not one of dramatic new experimental discoveries, each revising in some fundamental way our view of nature, as were the 1960's through the late 1970's. Indeed, even the $W^{\pm}$ and Z^0 were well anticipated by the existing Standard Model. Rather, there were substantial refinements in our knowledge and new questions posed which will ultimately demand a deeper understanding of the physics governing the accessible energy scales.

1.2 Experimental Outline and Highest Highlights

In what follows, we classify Fermilab research into the categories: (1) Heavy Flavor Production, (2) Kaon Physics including CP-violation, rare decay modes; (3) Hyperon Physics; (4) Electroweak Physics which includes neutrinos, muons, and QCD effects; (5) Dimuon Production and Hard Scattering; (6) Colliders, CDF, and Small Collider projects. Brief mention is made of the powerful assets that come from ACP and Theoretical Physics.

The highlights over the past decade in each of these categories, at least as now perceived, are the following, with details in subsequent sections:

Heavy Flavors

Here, E-691 is the clear winner with 13 publications in the past two years and "at least five more Phys. Rev. Letters expected, and some number of Phys. Reviews." This experiment studied photoproduction of charm, which follows the earlier E-516 and preceeds E-769, hadroproduction of charm. The basis of its success is over 10,000 fully reconstructed charm events, comparable to the total world sample of pre-existing data.

Kaon Physics
Here E-731 is the star with two publications and ". . about 10 more over the next two years" on the following subjects: ϵ'/ϵ, $K_L \to \pi^0 e^+ e^-$, $\pi^0 \to e^+ e^-$, $K_L \to e^+ e^- \gamma$, $K_L \to e^+ e^- e^+ e^-$, and charge asymmetry in K_{e3} decay. The precision in ϵ'/ϵ is expected to be the best yet.

Hyperon Physics
Here, a long and distinguished program was recently capped by the first measurement, by E-756, of the Ω^- magnetic moment. The yields of exotic hyperons in this research extends the world's supply by one or two orders of magnitude.

Electroweak Physics
Here E-616 provides half the data, in deep inelastic neutrino scattering, which gives the best determination of the Weinberg angle from the ratio NC/CC. The same research corrected a CERN normalization error in the absolute neutrino total cross-sections. Its successor is analyzing the largest sample ever of structure function data with 300,000 events caused by neutrinos of over 300 GeV.

Dimuons
The dimuon experiment of the decade was E-288 which announced the upsilon in June of 1978. The entire occupation of the world's laboratories with B-physics can be blamed on this research. The continuum data on Drell-Yan provided very precise measurements of proton structure functions. This experiment was succeeded by E-605 and E-772.

Collider Physics
CDF results from the first run in 1987 had, as probably its most important product, a wealth of experience and about 20 PhD students. As of this writing, several hundreds of $Z^o \to e^+ e^-$ and several thousands of $W \to$ leptons have been collected in the 1988 run, vastly extending the CERN data on these 1983/4 discoveries. These are simply a measure of the sensitivity of the '88 run which is expected to collect $\sim 4 - 5 pb^{-1}$ by May, 1988.

In a sense, the past decade was the "greening of Fermilab." Fermilab is now poised to be *the* premier scientific laboratory in the world during the decades to follow, before the "greening" of the SSC.

A set of seven tables serves as a snapshot of the experimental program of the Laboratory at present. Tables 1-4 list the titles and spokespersons of the active experiments, pending proposals and recently completed experiments. Table 5 is a simple statistical listing of Fermilab publications gleaned from SPIRES. Table 6 indicates the power of the increase in energy, duty factor and efficiency of the Tevatron as a fixed-target machine. Shown in Table 7 are two profiles of the Research program; Table 7a is a slice across the entire program for 1988/1989 while Table 7b is a cut along the program highlights for the last decade. Table 7a contains 1988/1989 publications but *only* from Physical Review Letters and Physics Letters. Table 7b is complementary to Table 7a in that it provides information on publications from the experiments highlighted in Section 1.2. A companion volume for this Table is "Publications from Fermilab Experiments" (November 1987) which lists all publications to that date.

As a map to the complete program, a table of *all* approved proposals at Fermilab with experiment number, title, spokesperson, and status is appended at the end of this report. That appendix can be used to cross reference the experiment numbers which appear in the margins in what follows.

Table 1. Currently Approved Fermilab Experiments.

FIXED-TARGET	
ELECTROWEAK	
E-665 (Montgomery)	Muon Scattering with Hadron Detection (13/79)
E-782 (Kitagaki)	Muon Scattering with Tohoku Bubble Chamber (7/33)
DECAYS AND CP	
E-761 (Vorobyov)	Hyperon Radiative Decay (6/16)
E-773 (Gollin)	Phase Difference Between η_{oo} and η_{+-} (4/12)
E-774 (Crisler)	Electron Beam Dump Particle Search (4/7)
E-800 (Johns/Rameika)	Ω^- Magnetic Moment (4/16)
HEAVY QUARKS	
E-687 (Butler)	Photoproduction of Charm and B (8/58)
E-690 (Knapp)	Hadronic Production of Charm and B (5/21)
E-760 (Cester)	Charmonium States (7/59)
E-771 (Arenton)	Beauty Production by Protons (9/68)
E-781 (Russ)	Large-X Baryon Spectrometer (7/26)
E-789 (Kaplan/Peng)	Production and Decay of B-Quark Mesons and Baryons (4/17)
E-791 (Appel/Purohit)	Hadroproduction of Beauty and Charm Particles (6/40)
HARD COLLISIONS AND QCD	
E-672 (Zieminski)	High P_T Jets and High Mass Dimuons (7/28)
E-683 (Corcoran)	Photoproduction of Jets (9/33)
E-704 (Yokosawa)	Experiments with a Polarized Beam (16/50)
E-706 (Slattery)	Direct Photon Production (9/75)
COLLIDER	
E-710 (Orear/Rubinstein)	Total Cross Section (6/18)
E-713 (Price)	Highly Ionizing Particles (2/3)
E-735 (Gutay)	Search for Quark Gluon Phase (7/52)
E-740 (Grannis)	D0 Detector (20/124)
E-741 (Shochet/Tollestrup)	Collider Detector at Fermilab (20/247)
E-775 (Shochet/Tollestrup)	Collider Detector at Fermilab (20/247)
E-775A/ E-775B (Shochet/Tollestrup)	Collider Detector at Fermilab (20/247)
OTHERS	
E-466 (Porile)	Nuclear Fragments (3/7)
E-754 (Sun)	Channeling Tests (4/8)
E-778 (Edwards)	Study of SSC Magnet Aperture Criterion (5/15)
E-790 (Sciulli)	ZEUS Calorimeter Module Tests (7/?)
E-793 (Lord)	Emulsion Exposure to 1000 GeV Protons (3/4)
E-795 (Pripstein)	Warm Liquid Calorimetry (6/19)
E-802 (Chatterjee/Ghosh)	Emulsion Muon Exposure (2/4)

NOTE: Numbers in parentheses denote total number of institutions and physicists, respectively.

Table 2. Pending Proposals.

P-682 (Underwood)	Polarized Beam
P-688 (Ditzler)	Polarized Beam
P-699 (Stanek)	Polarized Beam
P-783 (Reay)	Tevatron Beauty Factory
P-784 (Lockyer)	Bottom At The Collider
P-785 (Bonner/Pinsky)	Low Energy Antimatter
P-786 (Wilson)	Heavy Quarks With Muons
P-788 (Bernstein)	Neutrino Oscillations With Neutral Beam
P-794 (Van Bibber)	Construction And Operation Of An Axion Helioscope
P-796 (Thomson)	Measurement Of CP Violation Parameter η_{+-o}
P-797 (Gustafson/Thun)	SSC Detector Test - Fine-Grained EM Calorimeter
P-798 (Peterson/Rusack)	SSC Detector Test - Synchrotron Radiation Detector
P-799 (Wah/Yamanaka)	Search For The Decay $K_L \to \pi^o e^+ e^-$

Table 3. Fermilab Experiments Completed During 1985 Run.

E-605 (Brown)	Study of Leptons and Hadrons Near The Kinematic Limit
E-621 (Thomson)	A Measurement of the CP Violation Parameter η_{+-o}
E-691 (Witherell)	Photoproduction of Charm Particles
E-743 (Reucroft)	Charm Production in *pp* Collisions with LEBC
E-744 (Merritt)	Neutrino Charge Current Interactions (Lab E)
E-747 (Hahn)	Search of Fractionally Charged Particles
E-753 (Forster)	Channeling Studies

Table 4. Fermilab Experiments Completed in 1987-88 Fixed-Target Run.

FIXED-TARGET	
ELECTROWEAK	
E-632 (Morrison/Peters)	Wide Band Neutrinos in the 15' Bubble Chamber (16/84)
E-733 (Brock)	Neutrino Interactions with Quad Triplet Beam (4/26)
E-745 (Kitagaki)	Neutrino Physics with Quad Triplet Beam (10/43)
E-770 (Smith)	Neutrino Physics with Quad Triplet Beam (4/28)
DECAYS AND CP	
E-731 (Winstein)	Measurement of ϵ'/ϵ (5/27)
E-756 (Luk)	Ω^- Magnetic Moment (4/16)
HEAVY QUARKS	
E-653 (Reay)	Hadronic Production of Charm and B (19/79)
E-705 (Cox)	Charmonium and Direct Photon Production (8/47)
E-769 (Appel)	Pion and Kaon Production of Charm (8/25)
HARD COLLISIONS AND QCD	
E-711 (Levinthal)	Constituent Scattering (3/23)
E-772 (Moss)	Nuclear Antiquark Structure Functions (9/26)
OTHERS	
T-755 (Majka/Slaughter)	Streamer Chamber Tests (2/10)
E-776 (Baker)	Nuclear Calibration Cross Sections (3/7)

NOTE: E = Experiment; T= Test. Numbers in parentheses denote total number of institutions and physicists, respectively.

Table 5. Publications Statistics.

An examination of SPIRES elicits the following data: For the years 1974-1987 there are:	
1903	Journal publications based upon FNAL experimental research
309	PhD theses written
30,000	Citations to the above papers

A profile of the period 1984-87 indicates the break downs:

	'84	'85	'86	'87
Journal Publications	146	193	330	178
HEP Preprints, Reports, Meetings	292	398	481	427
Citations	1225	2291	943	1721

Our records show that 371 experiments have been completed out of 795 proposals submitted.

Table 6. Typical Before Tevatron and After Tevatron Experiments.

E-715	The Beta Decay of the Sigma Hyperon	
	1984, E-715 The previous world collection	80,000 events 400 events
E-621	CP-Violating Parameters Eta + - 0	
	1985, E-621 A total of eight earlier experiments	3×10^6 events 12000 events
E-744	Neutrino Scattering	
	1985, events with $E_\nu > 300 GeV$ Previous world total	300,000 0
E-605	Dileptons Produced by Protons	
	1985, E-605 with $\Delta p/p = 0.2\%$ Previous (E-288) with $\Delta p/p = 2\%$	20,000 Υ's 5,000 Υ's
E-731	CP-Violating Parameter ϵ'/ϵ	
	1987, E-731 $K_L \rightarrow 2\pi^o$ Predecessor E-617	300,000 events 3,000 events
E-756	Tevatron Hyperon Physics	
	1987, E-756 $\Omega^- \rightarrow \Lambda K^-$ Previous world total	100,000 events 16,000 events
E-691	Photoproduction of Charm	
	Total number of charmed decays fully reconstructed World's collection from all e^+e^- machines	10,000 events $\sim$ 8,000 events

Table 7a. 1988-89 Letter Publications.

1. Search for Highly Ionizing Particles at the Fermilab Proton–Antiproton Collider. P.B. Price *et al.*, Phys. Rev. Lett. 59, 2523 (1988).
2. Measurements of $D_s^{\pm}$ decays and Cabibbo-suppressed $D^{\pm}$ decays. J.C. Anjos *et al.*, Phys. Rev. Lett. 60, 897 (1988).
3. Azimuthal energy flow in deep-inelastic neutrino scattering. A. Mukerjee *et al.*, Phys. Rev. Lett. 60, 991 (1988).
4. Study of $D^o - \bar{D}^o$ mixing. J.C. Anjos *et al.*, Phys. Rev. Lett. 60, 1239 (1988).
5. Measurement of the Λ_c^+ lifetime. J.C. Anjos *et al.*, Phys. Rev. Lett. 60, 1379 (1988).
6. Neutrino production of same-sign dimuons. B.A. Schumm *et al.*, Phys. Rev. Lett. 60, 1618 (1988).
7. Multiplicity dependence of transverse-momentum spectrum for centrally produced hadrons in antiproton-proton collisions at $\sqrt{s} = 1.8$ TeV. T. Alexopoulos *et al.*, Phys. Rev. Lett. 60, 1622 (1988).
8. First result on a new measurement of ϵ'/ϵ in the neutral-kaon system. M. Woods *et al.*, Phys. Rev. Lett. 60, 1695 (1988).
9. Production of the $D_s^{\pm}$ by high-energy neutrons. C. Shipbaugh *et al.*, Phys. Rev. Lett. 60, 2117 (1988).
10. Nuclear-target effects in J/ψ production in 125-GeV/c antiproton and π^- interactions. S. Katsanevas *et al.*, Phys. Rev. Lett. 60, 2121 (1988).
11. Measurement of the nuclear slope parameter of the $\bar{p}p$ elastic-scattering distribution at $\sqrt{s} = 1800$ GeV. N.A. Amos *et al.*, Phys. Rev. Lett. 61, 525 (1988).
12. Transverse-momentum distributions of charged particles produced in $\bar{p}p$ interactions at $\sqrt{s} = 630$ and 1800 GeV. F.A. Abe *et al.*, Phys. Rev. Lett. 61, 1819 (1988).
13. Analyzing power measurement in inclusive π^o production at high X_F. B.E. Bonner *et al.*, Phys. Rev. Lett. 61, 1918 (1988).
14. D-meson production in 800 GeV/c pp interactions. R. Ammar *et al.*, Phys. Rev. Lett. 61, 2185 (1988).
15. New Limits on $K_{L,S} \rightarrow \pi^o e^+ e^-$. L.K. Gibbons *et al.*, Phys. Rev. Lett. 61, 2661 (1988).
16. Experimental investigation of non-linear dynamics in the Fermilab Tevatron. A. Chao *et al.*, Phys. Rev. Lett. 61, 2752 (1988).
17. Λ^o and $\bar{\Lambda}^o$ production from proton-antiproton collisions at $\sqrt{s} = 1.8$ TeV. S. Banerjee at al. Phys. Rev. Lett. 62,.12.(1989).

Table 7a. (continued)

18. Measurement of $D_s^{\pm} and D^{\pm}$ decays to nonstrange states. J.C. Anjos *et al.*, Phys. Rev. Lett. 62,.125.(1989).

19. Leading particle distributions in 200 GeV/c p+A interactions. K. Abe *et al.*, Phys. Lett. 200, 266 (1988).

20. Cross sections for neutrino production of charmed particles. N. Ushida *et al.*, Phys. Lett. 206, 375 (1988).

21. Production characteristics of charmed particles in neutrino interactions. N. Ushida *et al.*, Phys. Lett. 206, 380 (1988).

22. Jet production from nuclei at 400 GeV/c. H.E. Miettinen *et al.*, Phys. Lett. 207, 222 (1988).

23. Observation of $D^o \rightarrow K^o \bar{K}^o$. J.P. Cumalat *et al.*, Phys. Lett. 210, 253 (1988).

24. A new method to investigate the nuclear effect in leptonic interactions. T. Kitagaki *et al.*, Phys. Lett. 214, 281 (1988).

Table 7b. Letter Publications From Highlight Experiments.

E-691

1. An Experimental Study of the A-Dependence of J/ψ Photoproduction. Tagged Photon Spectrometer Collaboration. M.D. Sokoloff, *et al.*, Phys. Rev. Lett. $\underline{57}$, 3003 (1986).
2. Measurement of the D^+ and D^o Lifetimes. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{58}$, 311 (1987).
3. Measurement of the D_s^+ Lifetime. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{58}$, 1818 (1987).
4. Measurement of D_s^{+-} Decays and Cabibbo Suppressed D^{+-} Decays. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{60}$, 897 (1988).
5. A Study of $D^o\bar{D}^o$ Mixing. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{60}$, 1239 (1988).
6. Measurement of the Λ_c^+ Lifetime. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{60}$, 1379 (1988).
7. Measurement of D_s^{+1} and D^{+-} Decays to Nonstrange States. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{62}$, 125 (1989).
8. Charm Production Results from E-691: The Tagged Photon Spectrometer Collaboration. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{62}$, 513 (1989).
9. A Study of the Semileptonic Decay Mode $D^o \to K^- e^+ \nu_e$. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Submitted to Phys. Rev. Lett. Sept. 1988.
10. Experimental Study of the Semileptonic Decay $D^+ \to \bar{K}^{*o} e^+ \nu_e$. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Phys. Rev. Lett. $\underline{62}$, 722 (1989).
11. Observation of Excited Charmed Mesons. Tagged Photon Spectrometer Collaboration. J.C. Anjos, *et al.*, Submitted to Phys. Rev. Lett. Oct. 1988.

Table 7b. (continued)

E-731 (And Predecessors)

12. Measurement of ϵ in the Neutral Kaon System. E-731 Collaboration. R.H. Bernstein, *et al.*, Phys. Rev. Lett. 54, 1631-1634 (1985).

13. Measurement of the Ratio $\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_L \to \pi)$ Lepton Neutrino for K_L with 65-GeV/c Laboratory Momentum. E-731 Collaboration. D.P. Coupal, *et al.*, Phys. Rev. Lett. 55, 566-569. (1985).

14. Measurement of the K^{o*} (896) Radiative Width. E-731 Collaboration. D. Carlsmith, *et al.*, Phys. Rev. Lett. 56, 18. (1986).

15. First Result on a New Measurement of ϵ' / ϵ in the Neutral Kaon System. E-731 Collaboration. M. Woods, *et al.*, Phys. Rev. Lett. 60, 1695 (1988).

16. New Limits on $K_L, K_S \to \pi^o e^+ e^-$. E-731 Collaboration. L.K. Gibbons, *et al.*, Phys. Rev. Lett. 61, 2661 (1988).

E-756 (And Predecessors)

17. Polarization of Ξ^o and Λ Hyperons Produced by 400–GeV/c Protons. E-756 Collaboration. K. Heller, *et al.*, Phys. Rev. Lett. 51, 2025-2028 (1983).

18. Measurement of the Ξ^- Magnetic Moment. E-756 Collaboration. R. Rameika, *et al.*, Phys. Rev. Lett. 52, 581-584 (1984).

19. Measurement of the $\Sigma^o\Lambda$ Transition Magnetic Moment. E-756 Collaboration. P.C. Petersen, *et al.*, Phys. Rev. Lett. 57, 949-952 (1986).

E-616 (And Predecessors)

20. Measurement of the Rate of Increase of Neutrino Cross-Sections with Energy. E-616 Collaboration. R. Blair, *et al.*, Phys. Rev. Lett. 51, 343-346 (1983).

21. Measurement of $sin^2\theta_W$ and ρ in Deep Inelastic Neutrino–Nucleon Scattering. E-616 Collaboration. P.G. Reutens, *et al.*, Phys. Lett. 152B, 404 (1985).

22. Search for Neutral Heavy Leptons from Neutrino N Scattering. E-616 Collaboration. S.R. Mishra, *et al.*, Phys. Rev. Lett. 59, 1397-1400 (1987).

Table 7b. (continued)

E-605 (And Predecessors)

23. Atomic Number Dependence of the Production Cross-Sections for Massive Dihadron States. E-605 Collaboration. R.L. McCarthy, *et al.*, Phys. Rev. Lett. 40, 213 (1978).

24. Study of the High Mass Dimuon Comtinuum in 400-GeV Proton-Nucleus Collisions. E-605 Collaboration. D.M. Kaplan, *et al.*, Phys. Rev. Lett. 40, 435 (1978).

25. Correlations Between Two Hadrons at Large Transverse Momenta. E-605 Collaboration. R.J. Fisk, *et al.*, Phys. Rev. Lett. 40, 984 (1978).

26. A Search for New Massive Particles. E-605 Collaboration. R. Vidal, *et al.*, Phys. Rev. Lett. 77B, 344 (1978).

27. Study of Scaling in Hadronic Production of Dimuons. E-605 Collaboration. J.K. Yoh, *et al.*, Phys. Rev. Lett. 41, 684 (1978).

28. Evidence for the Υ'' and a Search for New Narrow Resonances. E-605 Collaboration. K. Ueno, *et al.*, Phys. Rev. Lett. 42, 486 (1979).

29. Scaling Properties of High Mass Symmetric Hadron and Pion Pair Production in Proton-Beryllium Collisions. E-605 Collaboration. H. Jostlein, *et al.*, Phys. Rev. Lett. 42, 146 (1979).

30. A-Dependence of the Inclusive Production of Hadrons with High Transverse Momenta. E-605 Collaboration. Y.B. Hsuing, *et. al.*, Phys. Rev. Lett. 55, 457 (1985).

31. A New Limit on Axion Production in 800-GeV Hadronic Showers. E-605 Collaboration. C.N. Brown, *et al.*, Phys. Rev. Lett. 57, 2101 (1986).

E-741 - (Collider Detector at Fermilab)

32. Transverse Momentum Distributions of Charged Particles Produced in $\bar{p}p$ Interactions at $s^{1/2}$ = 630-GeV and 1800-GeV. The CDF Collaboration. F. Abe, *et al.*, Phys. Rev. Lett. 61, 1819 (1988).

33. Measurement of the Inclusive Jet Cross-Section in $\bar{p}p$ Collisions at $s^{1/2}$ = 1.8-TeV. The CDF Collaboration. Phys. Rev. Lett. 62, (1989).

34. A Measurement of W Boson Production in 1.8-TeV $\bar{p}p$ Collisions. The CDF Collaboration. F. Abe, *et al.*, Phys. Rev. Lett. 62, 1005 (1989).

2 Fixed Target Experimental Results

2.1 Heavy Flavor Production

For many years charm spectroscopy was dominated by results from e^+e^- colliding beam facilities. This has changed dramatically in the past decade, due in large part to the advent of Silicon Microstrip Detectors (SMD's), which allow resolution of secondary vertices and result in a substantial improvement in signal–to–noise ratios in heavy quark Fixed–Target experiments. This allows one to capitalize on the enormous yields of charm particles in these experiments as compared to e^+e^- colliding beams. Indeed, such experiments at CERN and Fermilab have now eclipsed the e^+e^- colliding beam experiments as the major sources of detailed information about charmed particles. Fermilab experiments have obtained the most precise measurements of lifetimes of such particles as D–mesons and charmed baryons to date.

A large fraction of the world sample of fully reconstructed charm particles has been obtained in Fermilab Fixed–Target experiment E–691. This **E-691** has provided a great deal of quantitative information on charm spectroscopy, lifetimes, and production and decay characteristics. The high statistics samples available in such a Fixed–Target hadron experiment allows observation of the more evanescent particles, such as charm-strange baryons. With the Tevatron Upgrade it will be possible for future Fixed–Target experiments to observe a variety of expected new particles, charm-doubly strange, doubly charmed, etc., as well as study rare decay modes in greater detail.

Experiment 691 gathered data during the 1985 Fixed–Target using the Tagged–Photon beam in the Proton Lab. SMD's had been added since E-516 along with a number of other improvements. The photons were produced with an average photon energy of 145 GeV, and approximately one–half of the secondary vertices from charm decay could be identified with the SMD's. A total of one hundred million triggers were recorded during this one run containing approximately 10,000 fully reconstructed D's and 150 D_s^+; previously there were less than 1000 D's from all sources suitable for lifetime determinations.

The best determination of the lifetimes of the D^0 and D^+ were obtained by this experiment as shown in Figs. (1–4). The lifetime of the D_s^+ was determined and specific decay modes, $D_s^+ \to \phi\pi$ and $D_s^+ \to K^*K$ were seen. The Λ_c was observed and a precise measurement of its lifetime was also obtained. Also of fundamental importance, better limits, of order 0.4%, were placed upon $D^0 - \bar{D}^0$ mixing, superceding a previously claimed mixing at the 1% level. A "typical" E-691 event is shown in Fig. 5.

Experiment 743 measured the total charm production cross–section in a high–resolution Lexan Bubble Chamber (LEBC). Previous ISR results had suggested that the charm production cross–section increased by an order of magnitude between $\sqrt{s} = 27$ GeV and $\sqrt{s} = 50$ to 60 GeV, which cannot be
explained by QCD. E–743 results are fully consistent with QCD gluon–fusion **E-743**
production, showing less than a factor of two increase within this range. There is already good evidence from E–691 that charm photoproduction is well described by perturbative QCD. In fact, the agreement between both E–691 and E–743 with theory seems to be improved by inclusion of second–order QCD corrections. More precise measurements expected soon will help to resolve this issue, but it should be noted that this is a strong point of interface between theory and experiment.

A new round of experiments, E–687, E–771, E–789 and E–791 will soon **E-687**
begin to yield results from the recently upgraded multiparticle spectrome- **E-771**
ters. Many of the states of charm and beauty hadrons remain to be observed **E-789**
and studied, and Fermilab must look to its future role as a "factory" for such **E-791**
particles. This will be of greatly increasing interest as emerging theoretical techniques, for example numerical Lattice Gauge Theory calculations, make it possible to give quantitative theoretical predictions of masses, decay parameters, etc. within the framework of a rigorous treatment of QCD. It is widely believed that heavy quark systems will afford some essential simplifications which make them more amenable to immediate application of lattice methods, and thus the collection of a rich data base of experimental results is urgently needed.

An upgraded Tevatron is more effective in producing states which are hard to produce in e^+e^-, (*e.g.*, heavy flavor baryons). Charm baryon spectroscopy, in particular, has not been thoroughly investigated in e^+e^- collisions (nor have the D_s^+–meson decay properties). A variety of new effects come into play here because one is dealing with 3–body systems, one or more of the constituent quarks being quite massive. The meager data on charm–strange baryons all comes from hadron collisions in Fixed–Target experiments.

The spectroscopy of this menagerie of charm and bottom particles represents an extensive quantitative probe of the QCD dynamics which binds the quarks together into hadrons. Improving theoretical techniques should allow the measured numbers to confront theoretical predictions. Moreover, lifetimes and decay parameters contain detailed information about both the weak and strong interactions. Of perhaps greatest importance is the necessity of building a comprehensive data base of charmed states and decay modes. This will be extremely important in the eventual reconstruction of heavier flavor decay modes, such as B–mesons, where searches for rare decays and, *e.g.*, CP–violation effects will be of great interest.

Heavy quark phenomenology also encompasses an understanding of the production mechanism. Photoproduction and hadroproduction of charm and bottom are expected to take place primarily by photon–gluon and gluon–gluon fusion processes, respectively. Detailed studies of the longitudinal momentum distribution of charm particle production thus gives direct information on the gluon distribution function for hadrons.

On the theoretical side, perturbative QCD corrections to the basic parton process have been calculated. With the Tevatron Upgrade, a detailed study of the distributions and energy dependence of charm production along with a comparison between photoproduction and hadroproduction will provide extensive tests of the gluon–fusion model. Since gluon–fusion is the production mechanism for many of the exotic particles hypothesized by various extensions to the Standard Model (supersymmetry, technicolor, etc.), a reliable and tested understanding of this mechanism will allow more confident predictions for SSC physics.

Many other experiments have contributed to our knowledge of heavy quark production and spectroscopy. A short summary is provided in Table 8. The production of bound states of heavy quarks by incident hadrons, photons, and muons has been explored intensively. The energy, Feynman–
x, $p_\perp$ and A-dependence of J/ψ hadroproduction has been measured by **E-537**
E-537 and E-615. The latter experiment observed polarization of the J/ψ **E-615**
at Feynman–x close to 1. This is evidence for the so-called "higher twist"
effects. Υ production by hadrons has been studied by E-605 and E-772, the **E-605**
follow-up experiments to E-288 which discovered the Υ. Photoproduction **E-772**
of J/ψ has been studied in E-401, E-516, and E-691. Production of J/ψ
by incident muons was studied in E-203, which demonstrated the contribu- **E-203**
tion of the charm mass scale to the departure from Bjorken scaling. Charm

production by neutrinos in an emulsion target was studied in E-531. This experiment provided some of the best information on charmed particle lifetimes until it was surpassed by E-691. The A-dependence of charm hadroproduction was explored in two beam dump experiments, E-595 and E-613. Charm production by neutrons was studied by E-400, which observed the charmed-strange baryon, measured its lifetime, and also observed the rare decay mode $D^0 \to K_s^0 K_s^0$. The experiment also measured the ratio of D_s^+/D^0 production which allows one to predict the yield of ν_τ in hadronic collisions. **E-531** **E-595** **E-613** **E-400**

In the last run, 1987, several experiments acquired data which will add to our knowledge of heavy quark physics. These include E–705, which has taken data on the production of J/ψ via cascade from the χ–states. E–769 will study charmed hadroproduction by protons, pions, and kaons on a variety of nuclear targets, and E–687 will study charm photoproduction. Finally, E–653 will study production of charm by 800-GeV protons and 600-GeV negative pions. **E-705** **E-769** **E-653**

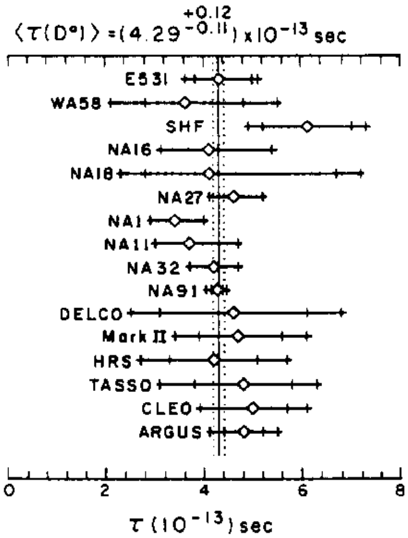

Fig. 1: Summary of D^0 lifetime results.

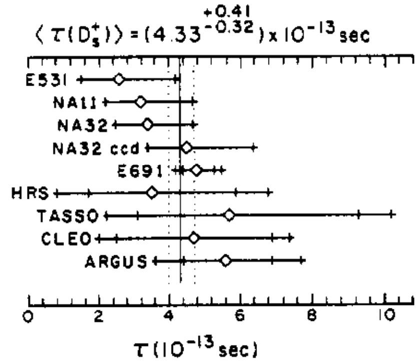

Fig. 3: Summary of D_s lifetime results.

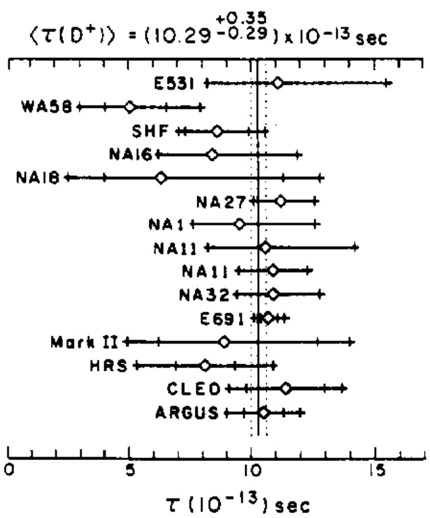

Fig. 2: Summary of D$^+$ lifetime results.

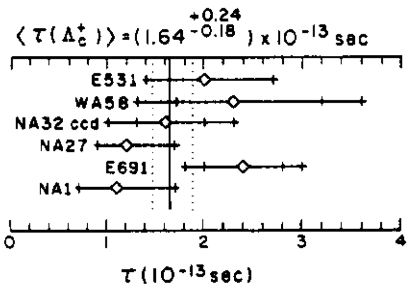

Fig. 4: Summary of Λ_c^+ lifetime results.

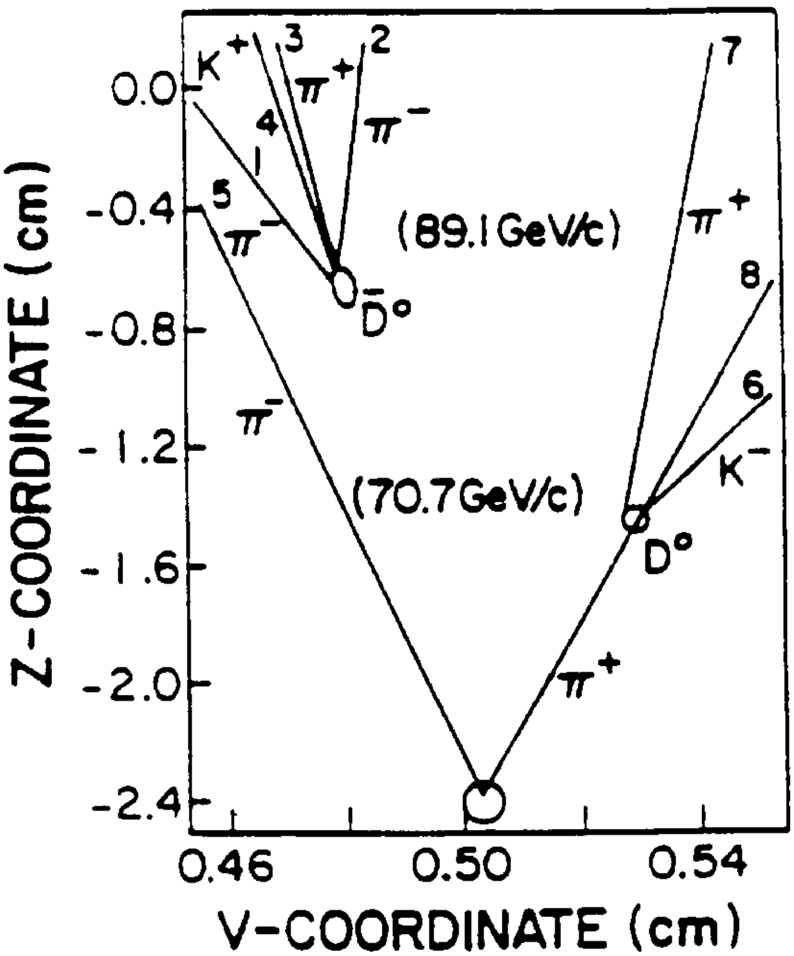

Fig. 5: A $D^0/\bar{D}^0$ event in E-691 showing track vectors and vertices (with error ellipses).

Table 8: Fermilab Heavy Flavor Experiments.

	Published results:
E-400	Charm Hadroproduction
E-531	Charm Particle Lifetimes/ $\nu_\mu - \nu_\tau$ mixing
E-516	Tagged Photon Spectrometer
E-605	Upsilon Production
E-691	Tagged Photon Spectrometer
E-743	Lexan Bubble Chamber/Multiparticle Spectrometer
	Results in preparation:
E-672	Hadronic States and High Mass Muons
E-687	Photoproduction of Charm and Beauty
E-769	Pion and Kaon Production of Charm
E-653	Hadronic Production of Charm and Beauty
E-705	Charmonium and Direct Photon Production

2.2 Kaon Physics

The first precise measurements of the nature of CP-violation were undertaken at Fermilab in 1980 beginning with E-617 and evolving into E-731 **E-617**
which yields a precision measurement of ϵ'/ϵ in the kaon system. This quan- **E-731**
tity, if measured to be nonzero, distinguishes between "milliweak" (Standard Model) and "superweak" theories of CP-violation. The value of ϵ'/ϵ, obtained by E-731 in a 1985 test run, was $0.003 \pm 0.003 \pm 0.002$. It was a surprise in that it was almost an order of magnitude smaller than some theoretical predictions. In a slightly later publication, subsequently CERN's NA31 reported a result of 0.003 ± 0.001, strongly hinting at "milliweak" CP-violation. Analysis of the full collected sample of E-731 data (three times more statistics than CERN with expected better systematics) should convincingly establish the milliweak effect if indeed $\epsilon'/\epsilon > 0.003$. A summary of Fermilab Kaon Physics results is given in Table 9.

This result influences our understanding of the weak interactions. Theorists were unable to produce a correct consensus prediction before the experiment. The measurement resolves a long-standing issue of the magnitude of the so-called "penguin diagrams" in nonleptonic weak processes. It was originally proposed that $\epsilon'/\epsilon \sim 1/50$, assuming penguin's dominate the nonleptonic weak decay $\Delta I = 1/2$ transitions. The present measurements clearly demonstrate that this is not the case. A better understanding of $\Delta I = 1/2$ transitions will have to await improved lattice QCD calculations, but irrespective of that, it remains of central importance to establish unambiguously the important parameter ϵ'/ϵ. E-731 will be reporting on its data during 1989.

We should emphasize that the future for kaon physics as a probe of potential new physics signatures is bright and is currently being considered as a major goal of any Tevatron Upgrade plan. New physics has often announced itself by producing feeble effects at rates proportional to $1/M^2$, where M is the new physics scale. For example, the weak interactions were discovered in β-decay reactions near the turn of the last century, while the W-boson discovery waited more than 80 years. The K-system allows a search for extremely small partial decay modes which may be the harbingers of physics beyond the Standard Model. The effective energy scales that can be probed are well beyond the energy scales directly probed in the SSC, while Fixed-Target kaon experiments are relatively inexpensive. A significant investment in a new facility with the capability of reaching branching ratio sensitivities of 10^{-10}/hour is required. Sensitivity to new thresholds up to two orders of magnitude beyond SSC energies could then be achieved.

For example, the decay mode $K_L \to \mu^+ e^-$ is forbidden in the Standard Model. If observed, however, at a level of 10^{-12} in branching ratio, it may imply the existence of a new force corresponding to the exchange of a new "Φ" boson with a mass scale of order 150 TeV and a typical weak coupling strength:

$$B.R.(K_L \to \mu^+ e^-) \sim 10^{-12} \left(\frac{150\ TeV}{m_\Phi}\right)^4 \left(\frac{g_\Phi}{g_2}\right)^4 \tag{1}$$

Moreover, for new physics in the SSC range the precision kaon experiments probe mixing angles of order 10^{-4}:

$$B.R.(K_L \to \mu^+ e^-) \sim 10^{-12} \left(\frac{2\ TeV}{m_\Phi}\right)^4 \left(\frac{\theta_\Phi}{10^{-4}}\right)^2 \tag{2}$$

The "bread and butter" of new precision kaon experiments must be to test the Standard Model in those ways that are special and novel to the kaon system. Primarily, this requires measuring processes that involve loops in the electroweak sector. For example, $K_L \rightarrow \pi^0 \bar{\nu}\nu$ involves a one–loop Feynman diagram dominated by the t–quark and a measurement can in principle determine m_t. There is further interest in these processes from the point of view of strong interaction chiral perturbation theory.

We are likely to learn more about CP–violation by finding new modes which involve combinations of parameters that are distinct from the combination defining ϵ. A promising candidate is $K_L \rightarrow \pi^0 e^+ e^-$, a mode that will be explored at the 10^{-11} level in future Tevatron runs.

The current best upper limit on the branching ratio comes from a partial analysis of the E-731 data. It is $B(K_L \rightarrow \pi^0 e^+ e^-) < 4 \times 10^{-8}$. The published **E-731**
CERN limit from NA–31 is comparable. A complete analysis will yield a sensitivity below 10^{-8} by 1990. This amplitude contains CP–even and –odd components, the latter going through photon (or Z^0) exchange and involving large t–quark loops. Rough estimates yield:

$$B.R.(K_L \rightarrow \pi^0 e^+ e^- \ \ CP - odd) \sim 0.5 \ - \ 4.0 \times 10^{-11}. \tag{3}$$

We see that the interesting new aspects of kaon physics begin at sensitivities to branching fractions of order 10^{-11} to 10^{-12}, implying a need to pursue a comprehensive program. Such physics is exciting and challenging and should be attractive to a large number of experimentalists. As early as 1978, Fermilab was beginning to study rare kaon decays with E-533, which measured the branching ratio of $K_L^0 \rightarrow (\pi^- \mu)$ atoms collecting 150 clean events for this rare ($BR \sim 4 \times 10^{-2}$) process.

Observation of CP-violation in three pion decays of the K_S^0 is particularly challenging and has so far eluded experimenters. The best limit to date for the parameter η_{+-0} comes from Fermilab E-621. There is a preliminary **E-621**
result of $\eta_{+-0} = 0.04 \ \pm \ 0.035$. In addition, this experiment has clarified a controversy on a claimed Lorentz noncovariance of kaon-system parameters with a measurement of the momentum dependence of the K_S^0 lifetime. No momentum dependence was observed and Special Relativity was confirmed. E-621 data now under analysis should reach a sensitivity an order of magnitude lower than the present limit. A value larger than roughly ϵ would

certainly signal unexpected physics. The E-621 group intends to definitively measure η_{+-0} in a new experiment currently under design.

Studies of kaon decays also probe other conservation laws. In particular, Fermilab E-773 will soon address CPT conservation with a measurement of the phase difference of the CP-violating kaon parameters, $\Delta\Phi = \mathrm{Arg}(\eta_{+-})$ - $\mathrm{Arg}(\eta_{00})$. This quantity is expected to be (essentially) zero but is currently measured to be $10^0 \pm 5^0$. **E-773**

Table 9: Fermilab Kaon Physics Experiments.

	Published Results
E-617	ϵ'/ϵ
E-731 test	ϵ'/ϵ, $K_L^0 \to \pi^0 e^+ e^-$
	Results in Preparation
E-621	η_{+-0}
E-731	ϵ'/ϵ, $K_L^0 \to \pi^0 e^+ e^-$

2.3 Hyperon Physics

Another important activity in the Fermilab Fixed–Target program is the study of the production, decay modes, and magnetic moments of hyperons. These investigations contribute to our fundamental knowledge of hadrons. Since the discovery at Fermilab in 1976 of inclusive hyperon polarization in hadroproduction, this effect has been confirmed and studied by several groups both at Fermilab and elsewhere. Hyperon beams at Fermilab are the highest energy polarized beams in the world. Precision measurements of the hyperon magnetic moments have been accomplished with these beams. As shown in Table 10, in all cases, the world averages of the magnetic moments are clearly dominated by results of experiments done at Fermilab. Another outstanding achievement in the hyperon program is the confirmation of the Cabibbo theory in the semileptonic decay of Σ^-.

Contrary to early expectations that spin effects are unimportant in high energy particle production, E-8 discovered significant Λ polarization in 300

GeV proton-beryllium inclusive reactions. This surprising result initiated a series of experiments which mapped out the details of this phenomenon. E-441 showed that Λ polarization also existed in proton-proton interactions, proving that it was not a nuclear effect. Another unexpected result, which came from E-555, was that the Λ polarization was still significant up to a transverse momentum of 3.5 GeV/c, whereas $\bar{\Lambda}$ was unpolarized up to 2.5 GeV/c. Furthermore, the magnitude of the Λ polarization in K^--proton inclusive reactions at 176 GeV/c was found to be large in E-663. It was realized in E-495 that Ξ^0 was polarized in a similar fashion. In 1979 and 1980, charged hyperons were extensively studied at 400 GeV in E-497 and E-620. Both experiments have demonstrated that inclusive polarization was a common feature in the production of hyperons. Recently, E-756 has collected the largest sample of Ω^- in the world, 100,000 events, and discovered that, when produced by protons, the Ω^- is not significantly polarized. Other hyperons are also accepted by their trigger, for example, Figure 6 shows 80,000 Ξ^- events from E-756. By now, much has been learned about the hyperon polarization phenonemon. However, there remain some fundamental mysteries and a theoretical understanding of its origin has yet to emerge.

E-8 **E-441** **E-555** **E-663** **E-495** **E-497** **E-620** **E-756**

Exploiting the polarization phenonemon and the fact that hyperons are copiously produced at Fermilab, hyperon magnetic moments can be precisely determined using the spin-precession technique. The magnetic moment of the Λ was measured to a precision of better than 1% in E-440, a factor of ten in improvement of the world average. Encouraged by the first determination in E-440, E-495 was then performed to measure precisely the magnetic moment of Ξ^0. To date, these are the only results for Ξ^0 in the world. It was natural to extend the definitive measurements to all charged hyperons (E-497, E-620, and E-715), as well as the $\Sigma^0 - \Lambda$ transition moment using the Primakoff effect (E-619). In 1988, a combination of spin-transfer and spin-precession has been used in E-756 to make the first measurement of the magnetic moment of the Ω^-. In the near future, E-800 will continue this measurement, improving the precision by a factor of 5. We should mention that the hyperon-magnetic moments are in good agreement with the conventional flavor-SU(3) predictions. A summary of the moment data appears in Table 10.

E-440 **E-495** **E-715** **E-619** **E-756**

In addition to the magnetic-moment measurements, rare decays have also been studied. A significant result came from E–715 in the 1983–84 maiden

E-715

run of the Tevatron. A longstanding problem for the Cabibbo theory of weak currents was the asymmetry parameter of Σ^-–β-decay, which seemed to be consistently yielding the wrong sign in five previous low statistics experiments. E–715 collected 50,000 such events and confirmed unambiguously the correct sign predicted by the consistency of the Cabibbo structure of the hadronic weak current. The precise measurement of g_A/g_V for $\Lambda \to pe\nu$ in E-361 also contributes to our understanding of the weak interactions in **E-361** hadron decays. A summary of hyperon experiments is given in Table 11.

The study of rare radiative weak decays will probe the structure of hadrons and should bring the increasing wealth of data into contact with current theoretical programs. In E-619, the branching ratio and asymmetry parameter for **E-619** $\Sigma^0 \to \Lambda\gamma$ were determined for the first time. In the upcoming Fixed–Target run, E–761 will measure the branching ratios and asymmetry parameters **E-761** for the decays $\Sigma^+ \to p + \gamma$ and $\Xi^- \to \Sigma^- + \gamma$. The diagrams which describe these radiative decays have common features with those of interest in other processes, *e.g.*, the $\Delta I = \frac{1}{2}$ rule in nonleptonic weak decays and ϵ'/ϵ in CP–violating kaon decays. Comparison of the predicted and measured decay rates and asymmetry parameters will offer a unique opportunity to study the interplay of weak and electromagnetic effects.

A new experiment, E–781, will exploit the copious flux of hyperons to **E-781** produce leading charmed baryons. This technique will open a window on charmed–baryon spectroscopy and production dynamics, and samples of order $\sim 10^6$ detected charmed baryon decays per run are planned.

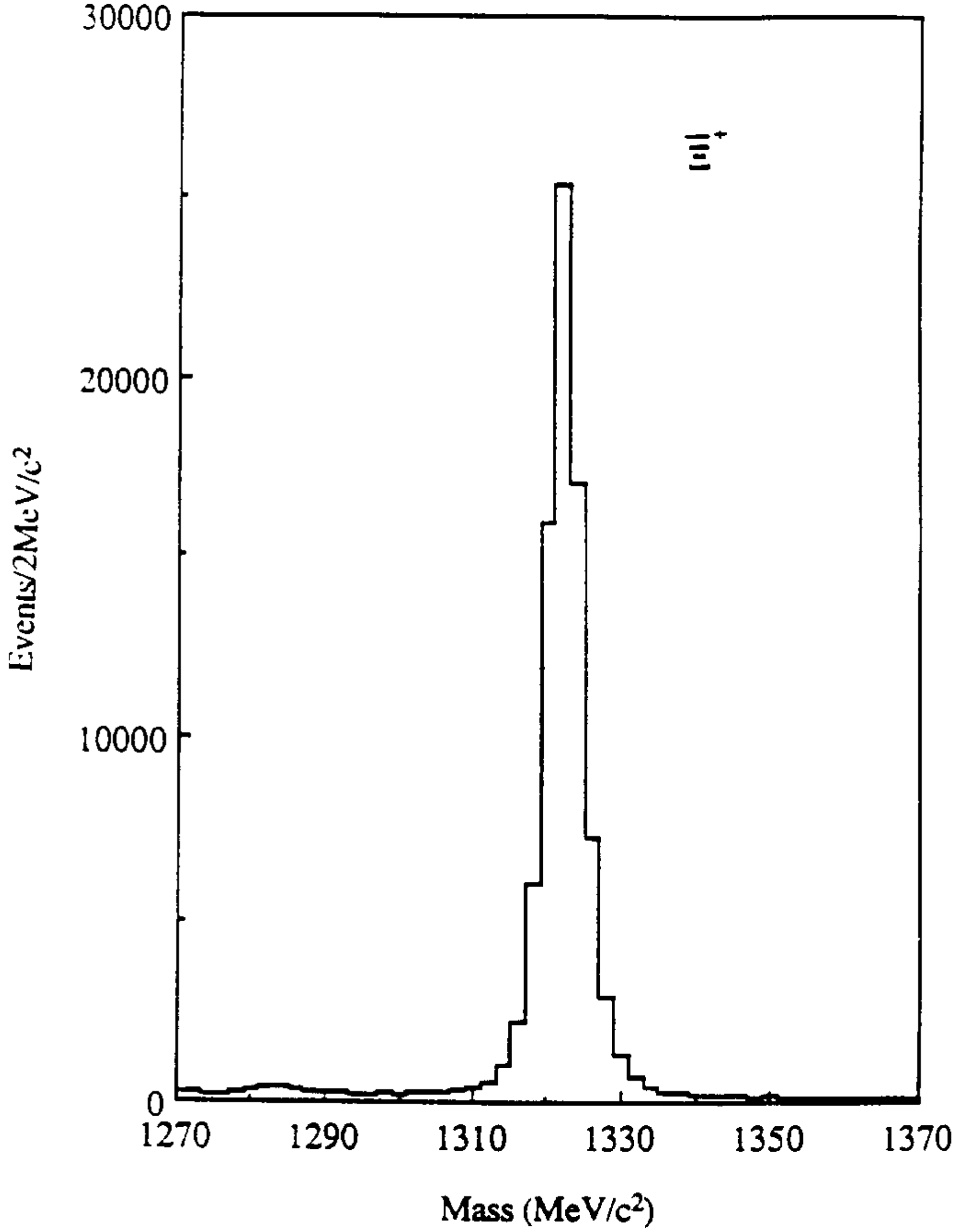

Fig. 6: Invariant mass plot for anti- Ξ^- decays from E-756 data.

Table 10: Fermilab Hyperon Magnetic Moment Measurements.

Particle	World Average	Fermilab Measurement
Λ^0	-0.613 ± 0.004	-0.613 ± 0.004 (E–440)
		-0.606 ± 0.015 (E-495)
Σ^+	2.42 ± 0.05	2.38 ± 0.02 (E–497)
		2.48 ± 0.03 (E–620)
Σ^-	-1.157 ± 0.025	-0.89 ± 0.14 (E–620)
		-1.23 ± 0.05 (E–497)
		-1.17 ± 0.015 (E–715)
$\Sigma^0 \to \Lambda^0$	1.61 ± 0.08	-1.59 ± 0.09 (E-619)
Ξ^0	-1.25 ± 0.014	-1.20 ± 0.06 (E–440)
		-1.253 ± 0.014 (E–495)
Ξ^-	-0.693 ± 0.040	-0.69 ± 0.04 (E–620)
		-0.65 ± 0.02 (E–756)
		-0.66 ± 0.05 (E-715)
Ω^-		-2.0 ± 0.2 (E–756)

Table 11: Fermilab Hyperon Physics Experiments.

	Published Results
E-361	Λ^0 β–decay
E-495	Ξ^0 Magnetic Moment
E-497	Charged Hyperon Production and Magnetic Moments
E-555	Λ^0 Polarization at High–p_T
E-619	$\Sigma^0 \to \Lambda^0$ Transition Moment
E-620	Charged Hyperon Magnetic Moments
E-663	Λ^0 Polarization in $(p,\ \bar{p},\ K^-) + p \to (\Lambda,\ \bar{\Lambda}) + X$
E-715	Σ^- β–decay
	Results in Preparation
E-756	Ω^- Magnetic Moment

2.4 Electroweak Physics

Two of the components of the current Standard Model are the electromagnetic and weak theories combined in the late sixties by Glashow, Salam, and Weinberg. Experiments with neutrinos, electrons, and muons formed the basis for this theory and with the discovery of neutral currents in the early seventies a piece of the model was confirmed. The understanding of this sector of the theory is in some sense more mature than that of the hadronic sectors. This situation has led to a continuing series of experiments which use the electromagnetic and weak interations as probes of nature. On the other hand, attempts to understand the Standard Model (both its hierarchy of flavors and its basic couplings) frequently rely on measurements with neutrinos and charged leptons. Picking just two of these results for special mention one can cite:

- The determination of the Weinberg angle from the ratio of neutral to charged currents in neutrino quark scattering. The present world average gets half its statistical precision from Fermilab experiments. One such experiment, E-616, by itself finds: **E-616**

$$\sin^2 \theta_W = 0.239 \pm 0.008 \pm 0.006 \tag{4}$$

  The second of the errors involves an evaluation of uncertainties coming from quasi-theoretical sources such as the mass of the charm quark.

- An understanding of the relationship between the generations is missing from the Standard Model. However, there have been many searches for transitions between different generations. One of the most sensitive limits on the occurrence of transitions between muon neutrinos and tau neutrinos comes from the E-531 emulsion experiment published in **E-531** 1986.

The decade 1978-1988 has been a period of tidying up in neutrino physics while at the same time searching for chinks in the armour of the Standard Model. Two areas of anomaly in weak interactions in the early part of the decade concerned 'prompt neutrino fluxes and like sign dimuons.'

The measurement of prompt neutrino fluxes (that is neutrinos not originating from pion or kaon decay) had been studied in a series of 'beam dump' experiments. Several such experiments had been conducted at CERN and there were indications of a violation of electron-muon universality. Experiment **E-613** E-613 resolved this anomaly by performing an experiment in which the sources of spurious signal, from production of neutrinos upstream of the final target, were carefully eliminated.

There was a series of measurements of 'like sign' di-lepton production by neutrinos which indicated a yield in excess of that expected from conventional sources. In this context charm production and decay is understood to be conventional. E-744, working with the 800 GeV protons available from the **E-744** Tevatron, published what appears to be the definitive result in 1988. The higher energy, high luminosity, and careful evaluation of backgrounds leads to the conclusion that the like-sign dimuon yield is in fact (within rather small errors) that expected from the various sources within the Standard Model.

A search for heavy neutral leptons was made by several experiments both in muon and neutrino beams. Of note are the limits set by the muon experiment E-391 and that of E-616 using the 600 ton neutrino detector. In the **E-391** mass range 0.25-14 GeV, no heavy neutral leptons were found with a limit **E-616** on the coupling of 10^{-3} times the Fermi strength.

The masses of the three neutrinos have remained elusive. It seems at the moment that neutrino oscillation experiments may be the only way of detecting very small masses in the $10^{-4} - 10^{-6}$ eV range. Three Fermilab experiments have set very stringent limits on the mixing parameters between the neutrino species, as seen in Table 12.

Experiment E-53 managed to establish their limit using a H-Ne filled **E-53** bubble chamber in an exposure with a neutrino beam with a small and known contamination of electron neutrinos. E-531, in a tour de force experiment, **E-531** searched for a tau lepton produced by neutrinos in a nuclear emulsion. No tau lepton decays were found in some 1200 muon neutrino induced events. This measurement is the best limit up to the present time. Finally, E-701 searched **E-701** for the difference in muon neutrino rates in the two detectors deployed at two distances in the same neutrino beam. By varying the neutrino energies, a search was made for a difference in the ν_μ rates in the two detectors which would have signalled the existence of oscillations.

Although the negative results described here are in one sense disappointing, their results form the justification for using the electromagnetic and weak interactions as 'understood' probes of hadronic matter which we turn to now.

A third cornerstone of the Standard Model is Quantum Chromodynamics (QCD), the theory of the strong interactions between quarks. QCD weaves through all topics but nestles intimately with electroweak interactions in the matter of quark structure functions. One of its manifestations, originally seen at Fermilab in the 1970s, is the scaling violation in the structure functions measured in deep inelastic scattering. Since then the understanding of scaling violations due to QCD radiative corrections in the structure functions has advanced. The early values of Λ_{QCD} were approximately 700 MeV. After 10 years, the accepted range is 100-200 MeV. Major contributions to the measurement of Λ_{QCD} come from BFP(E-203/E-391) and E-616. BFP was **E-203**
the first experiment to establish the contribution of the threshold for charm **E-391**
production to scaling violations. Another important contribution was the definitive determination by E-616 of the neutrino total cross-section. At the **E-616**
present time such measurements are arguably the best determination of the QCD coupling constant.

Muons scatter through the exchange of virtual photons. The effects due to the hadronic component in the photon had long been sought. The first indications of shadowing at high momentum transfer came from E-448. Be- **E-448**
yond this effect, the distributions of quarks in nucleons are now known to depend on the nucleus in which they reside. There are experiments with the 15' Bubble Chamber and from E-745 which add to our understanding of this **E-745**
relatively subtle phenomenon.

Study of the final state in lepton interactions provides comparatively direct information on the underlying parton interactions. E-180 and E-545 **E-180**
with the 15' Bubble Chamber both contributed a series of publications on **E-545**
this subject. In addition, using a deuterium fill, E-545 was able to establish the similarity of the majority quark distributions in the proton and neutron and their difference from the minority quark distribution.

QCD can also manifest itself in the distributions of the final state hadrons and in 1980 the muon experiment, E-398, observed in the P_t distributions the **E-398**
characteristics of quark gluon bremsstrahlung. At roughly the same time the E-180, E-545, and E-546 experiments with the 15' Chamber also published evidence for QCD effects. It is interesting that E-594 recently published a **E-594**
measurement of the azimuthal distribution of the hadronic final state about

the virtual boson direction. This was an experimental and analysis triumph for a multi-ton calorimetric detector.

The new phase of lepton scattering experiments (E-665, E-733, E-744, E-745, and E-770) with the 800 GeV Tevatron is expected to soon produce a flood of new information.

Table 12: Fermilab Neutrino Oscillation Experiments.

Experiment	Method	$\sin^2\theta$ - limit	Mass Range
E-53	15' Bubble Chamber	$\nu_\mu \to \nu_e \leq 0.01$	1 - 100 eV
E-531	Nuclear Emulsion	$\nu_\mu \to \nu_\tau \leq 0.001$	1 - 100 eV
E-701	2 element detector	$\nu_\mu \to \nu_x \leq 0.02$	10 - 1000 eV

2.5 Dimuon Production and Hard-Scattering Experiments

The hadron–induced reactions with the cleanest theoretical interpretation are those in which two constituents collide to produce a gauge boson; a virtual–photon, a W or Z, or a vector meson, such as the J/ψ or Υ. The experimental signature for such reactions is especially clean when the produced particle decays to a pair of muons, an approach pioneered by Lederman *et al.* in 1970. In the 1970's, dimuon experiments at Fermilab with proton beams made the first measurements of nucleon structure by this technique, and also discovered the Υ family of mesons. Experiments with pion beams provided the first measurments of the quark structure of the pion.

In the 1980's dimuon experiments have continued with second–generation detectors to yield high–statistics measurements that provide important tests of QCD. The results are of comparable statistical and systematic significance to related measurents via deep–inelastic lepton–hadron scattering, and provide information on a different combination of nucleon–structure parameters than is accessible in the latter experiments. The dimuon experiments have particular impact on questions of nucleon structure for constituents with very low momentum fraction and on pion structure at large x.

The measurements of 500,000 dimuons with invariant mass above 8 GeV/c^2
in proton interactions at 800 GeV (E–605, E–772, and also $\bar{p}$ interactions in **E-605**
E–537) test, to second–order in perturbation theory, the QCD–based relation **E-772**
between deep–inelastic lepton–hadron scattering and Drell–Yan dimuon pro- **E-537**
duction. A subset of the E-605 data is shown in Fig. 7. They are essential
for extracting reliable values of Λ_{QCD}, the fundamental mass parameter of
the strong interactions. These measurements also yield the most precise de-
termination of the antiquark distribution in a nucleon. The measurement of
70,000 dimuons with mass above 4 GeV/c^2 produced with high–energy pions
(E–615 and E–326) measures uniquely and accurately the parton structure **E-615**
of the pion and tests the detailed higher order QCD–description of pion in- **E-326**
teractions.

The details of charm and beauty quarkonium production also seen in the
dimuon experiments (and E-672) provide important tests of the gluon–fusion **E-672**
mechanism for heavy quark production, and provide the foundation for the-
oretical predictions of top–quark production and searches for states outside
the Standard Model. A simple example is the search for the "Darmstadt
axion" which E–605 completely ruled out. **E-605**

A more detailed understanding of parton distributions in hadrons is going
to require large samples of high–energy, high–Q^2 deep–inelastic scattering
data which can be compared with this dimuon data. E–665 in the Fermilab **E-665**
high–energy muon beam is the only apparent source of such data in the near
future.

Further important tests of our present understanding of parton interac-
tions are provided by the direct–photon production measurements of E–705 **E-705**
and E–706 and the photoproduction of high–$p_\perp$ hadrons which is being sur- **E-706**
veyed by E–683. These data will yield the most direct measurement of the **E-683**
gluon distribution in nucleons. The measurement of jet production in hard **E-557**
hadron collisions has also been studied by E-557 and E-609. A summary **E-609**
table of relevant Fermilab experiments is given in Table 13.

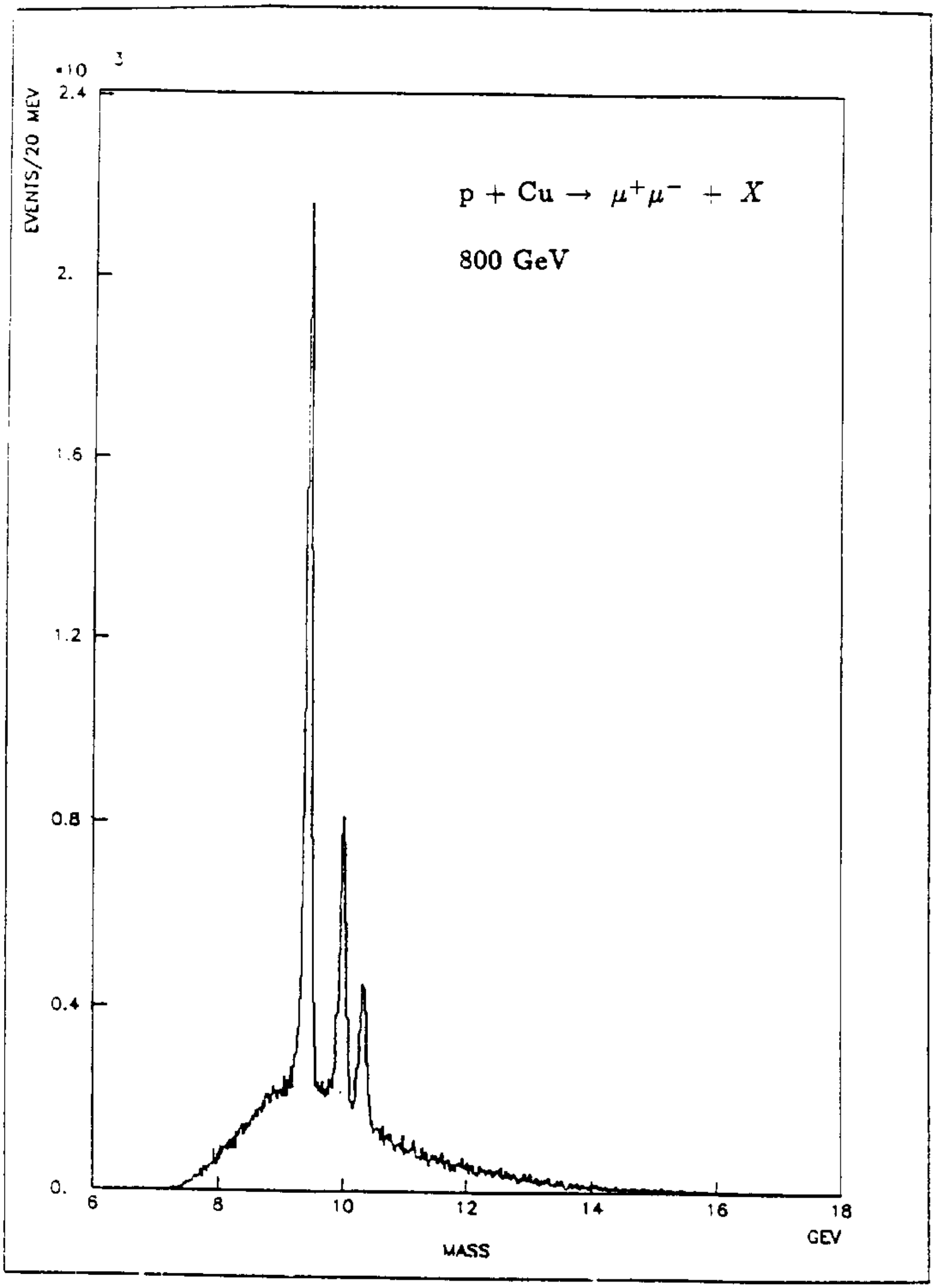

Fig. 7: Dimuon mass spectrum observed in E-605.

Table 13: Fermilab Dimuon and Hard–Collision Experiments.

	Published Results
E-605	Upsilon and Drell-Yan Dimuons
E-326	Production of Dimuons by Pions
E-615	Forward Production of Dimuons by Pions
E-537	Antiproton Production of Dimuons
E-557	Jet Production
E-609	High $p_{\perp}$ Jets
	Results in Preparation
E-665	Deep-Inelastic Muon Scattering with Hadron Detection
E-672	Dimuons and Jets
E-683	Photoproduction of High-Pt Hadrons
E-705	Charmonium and Direct Photon Production
E-706	Direct Photon Production
E-772	A-Dependence of Dimuon Production

3 The Tevatron Collider

3.1 Construction and Commissioning of Tevatron

The late spring of 1982 saw the end of the 400–GeV running with the old Main Ring and the beginning of the final installation of the Tevatron. Most of the preparation work was complete, *e.g.*, Accelerator quality magnets were delivered from the Magnet Facility at a rate of more than ten per week for the prior 18 months. The rf, controls, power supply, quench protection, vacuum correction, injection and extraction systems were ready to be installed. The massive cryogenic system with its Central Helium Liquefier and 24 satellite refrigerators was mostly in place.

In the end of May, 1983, the machine was complete and at its operating temperature. The first turn of beam around the Tevatron was achieved on June 2, with coasting beam following on June 26. Acceleration to 512 GeV occurred in July and 700 GeV was reached on August 15. A five month Fixed–Target run at 400 GeV commenced in October, 1983 and in April, 1984, the energy was doubled to 800 GeV.

A full–fledged 800 GeV Fixed–Target run began on January 1, 1985, and continued into August. Beam was delivered to 14 experiments using a 23 second slow spill with three fast pulses evenly interspersed. A total of 1.38×10^{18} protons were delivered during this 33 week run. Statistics for Fixed-Target operation during 1985 and 1987 are shown in Figures 8 and 9.

Following this run preparations were made to commission the Tevatron Collider. The first accumulation of antiprotons was accomplished in September; by October the stacking rate had reached 10^9 antiprotons/hour and 10^{10} antiprotons had been stacked in the Accumulator core. The first $\bar{p} - p$ collisions (at 1.6 TeV) were observed on October 13, 1985. The Accelerator was then shut down to construct the D0 Collider Detector building and install an overpass to carry Main Ring beam over the CDF detector.

The first use of the Tevatron for Collider physics began in January 1987 and continued until May. An integrated luminosity of ~ 70 inverse nanobarns was delivered to CDF at a center–of–mass energy of 1.8 TeV. A peak initial luminosity of $\sim 1.5 \times 10^{29}$ $cm^{-2}sec^{-1}$ was attained. During this period four experiments took data and all have published at least one paper. A graphical representation of Collider operations during both 1987 and 1988 is shown in Figures 10, 11, and 12.

The second Tevatron Fixed–Target run began on June 1, 1987, and ended on February 15, 1988, with an integrated intensity of 2.19×10^{18} protons delivered to 16 experiments during the 35 week run. Peak extracted intensity reached 1.8×10^{13} protons/pulse and the averaged Tevatron intensity per pulse for the entire run was 1.2×10^{13}.

Presently the Tevatron is operating in the Collider mode at an energy of 900 GeV (1.8 TeV in the center–of–mass), using six proton bunches with $\sim 10^{11}$ protons per bunch, and six antiproton bunches with $\sim 3 \times 10^{10}$ $\bar{p}$'s per bunch. The highest luminosity achieved to date is 2.06×10^{30} $cm^{-2}sec^{-1}$, far exceeding its design luminosity of 10^{30}. There have been over 150 stores conducted with an average duration of 13.7 hours and an average integrated luminosity of 25 nb^{-1} (the maximum integrated luminosity for one store has been as high as 135 nb^{-1}). The average $\bar{p}$ stacking rate for this run is $\sim 1.1 \times 10^{10}$ antiprotons/hour with a peak rate of over 1.9×10^{10} recorded. The largest stack accumulated to date is over 8×10^{11}.

Fermilab has built the first successful superconducting synchrotron and $\bar{p}p$ Collider. This success has had a profound effect on the field of High Energy Physics. Without the Tevatron it is very likely that the West Germans would not be building HERA, the Soviets would not be building UNK, CERN would not be contemplating the LHC, nor would the U.S. be proposing to build the SSC. The $\bar{p}p$ Collider, in turn encouraged by the success of CERN's AA ring, opens up a very rich vein of physics. In the early stages the aim will be on the highest possible energy, but gradually (as the SSC comes on) it will turn towards more specialized kinds of research using a multitude of more specialized (and cheaper!) detectors.

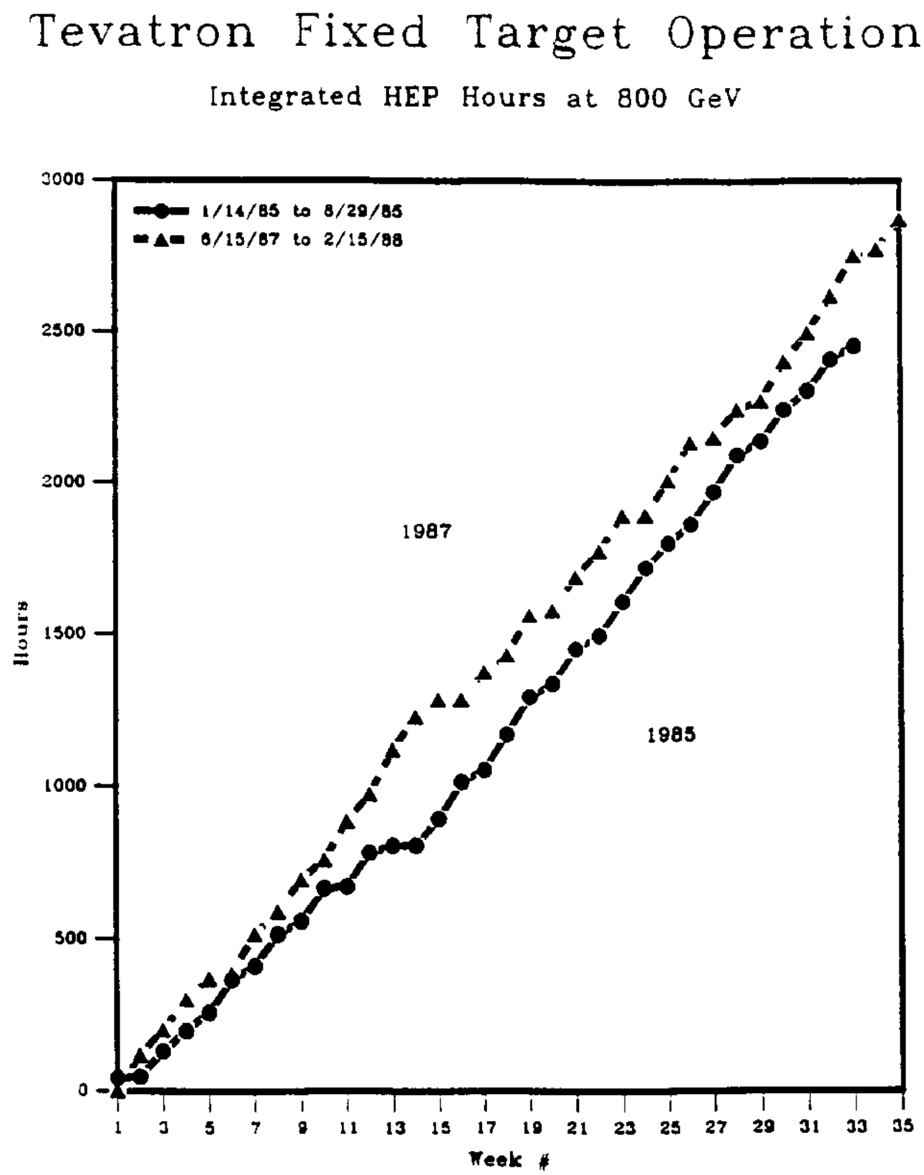

Fig. 8. Tevatron Fixed-Target HEP hours for the 1985 and 1987 runs.

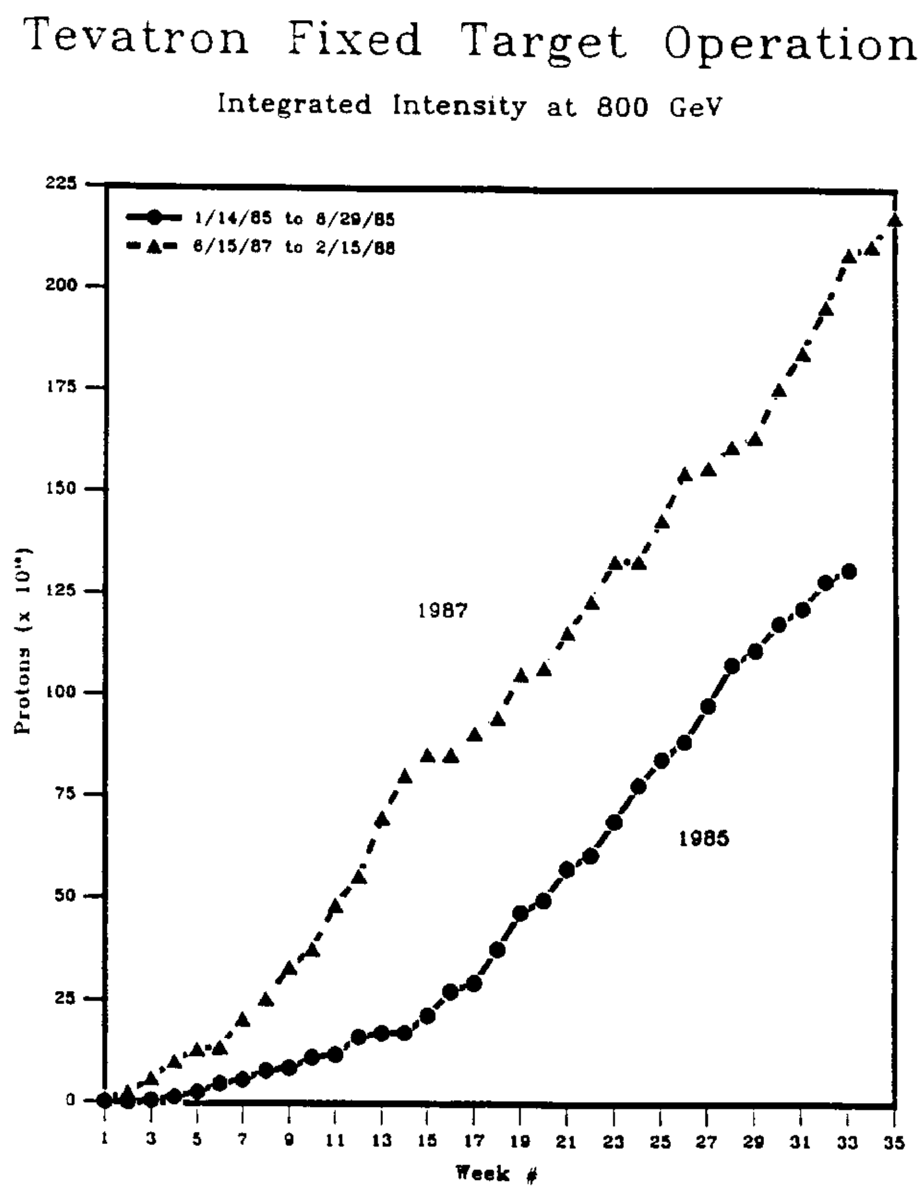

Fig. 9. Tevatron Fixed-Target integrated intensity for the 1985 and 1987 runs.

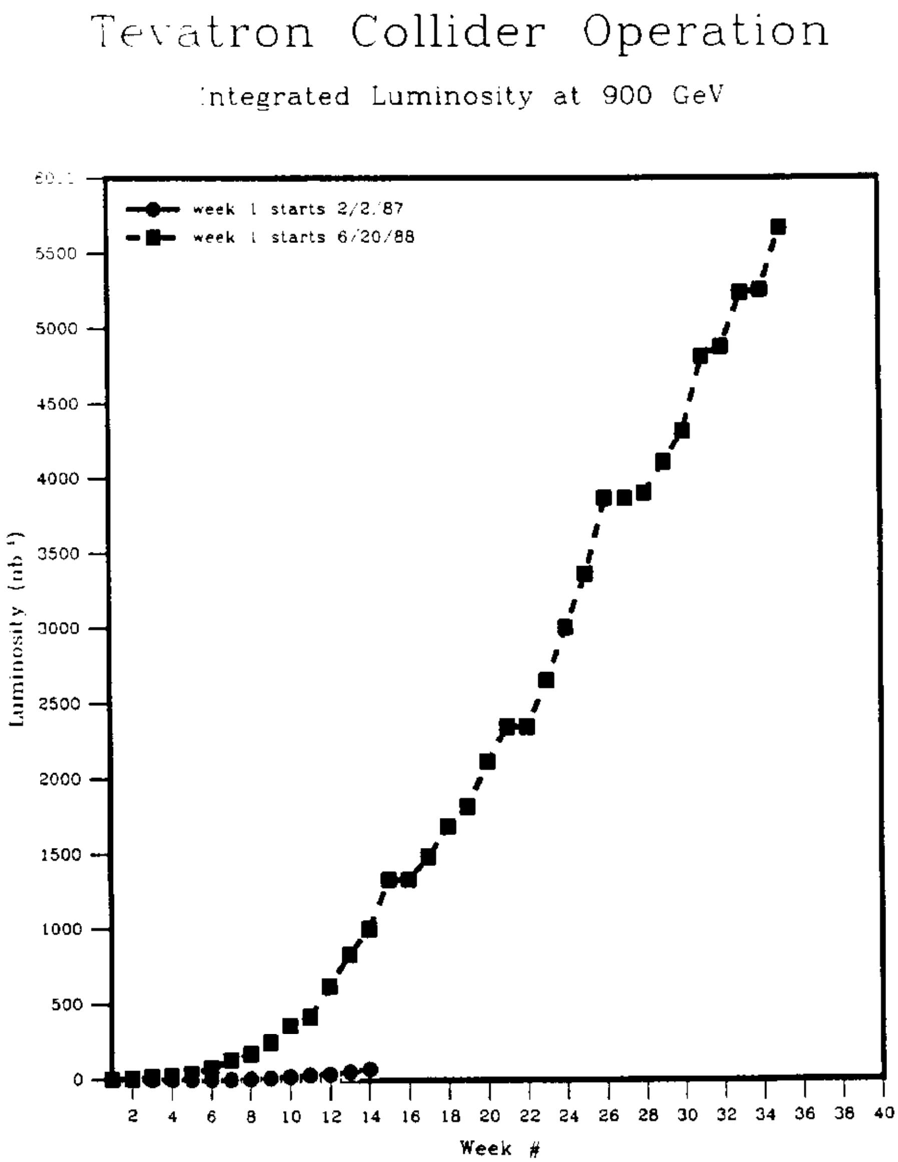

Fig. 10. Tevatron Collider integrated luminosity for the 1987 and 1988 runs.

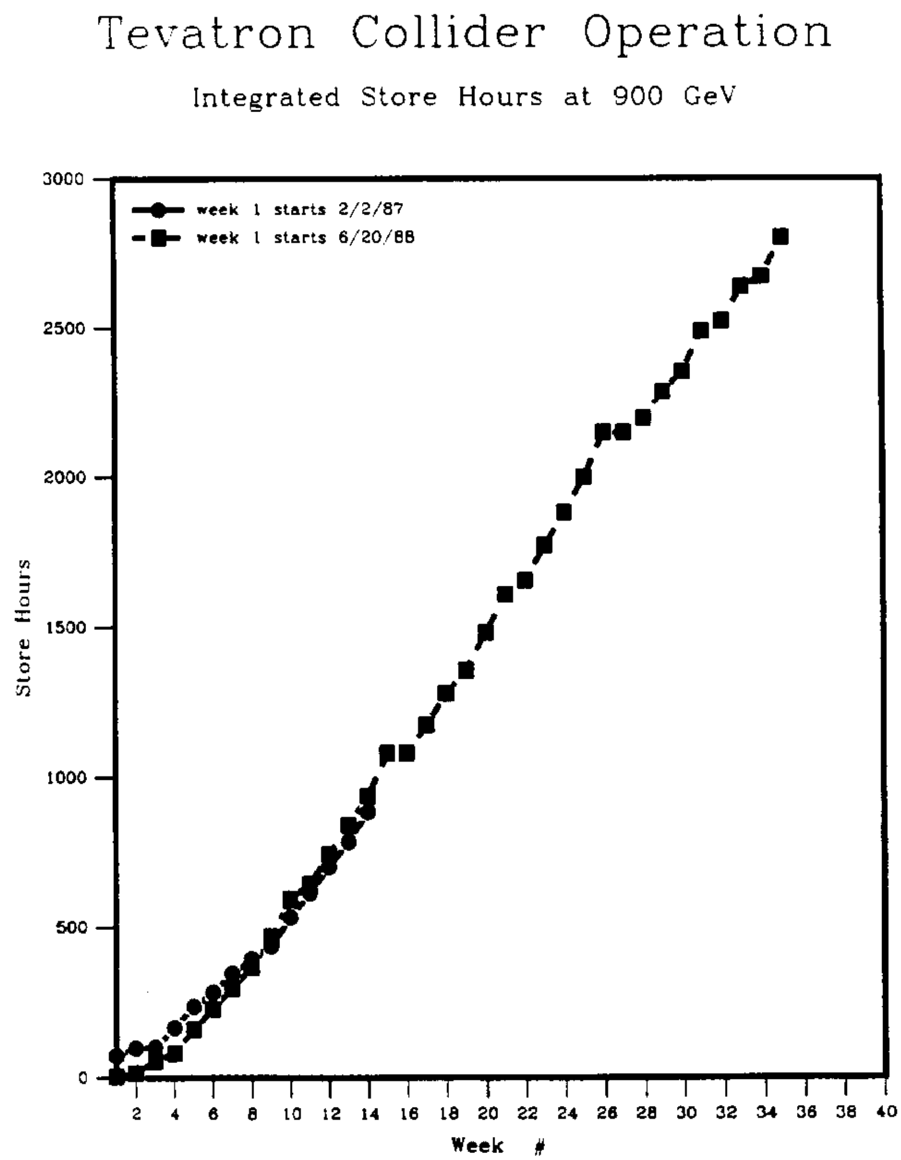

Fig. 11. Tevatron Collider integrated hours for the 1987 and 1988 runs.

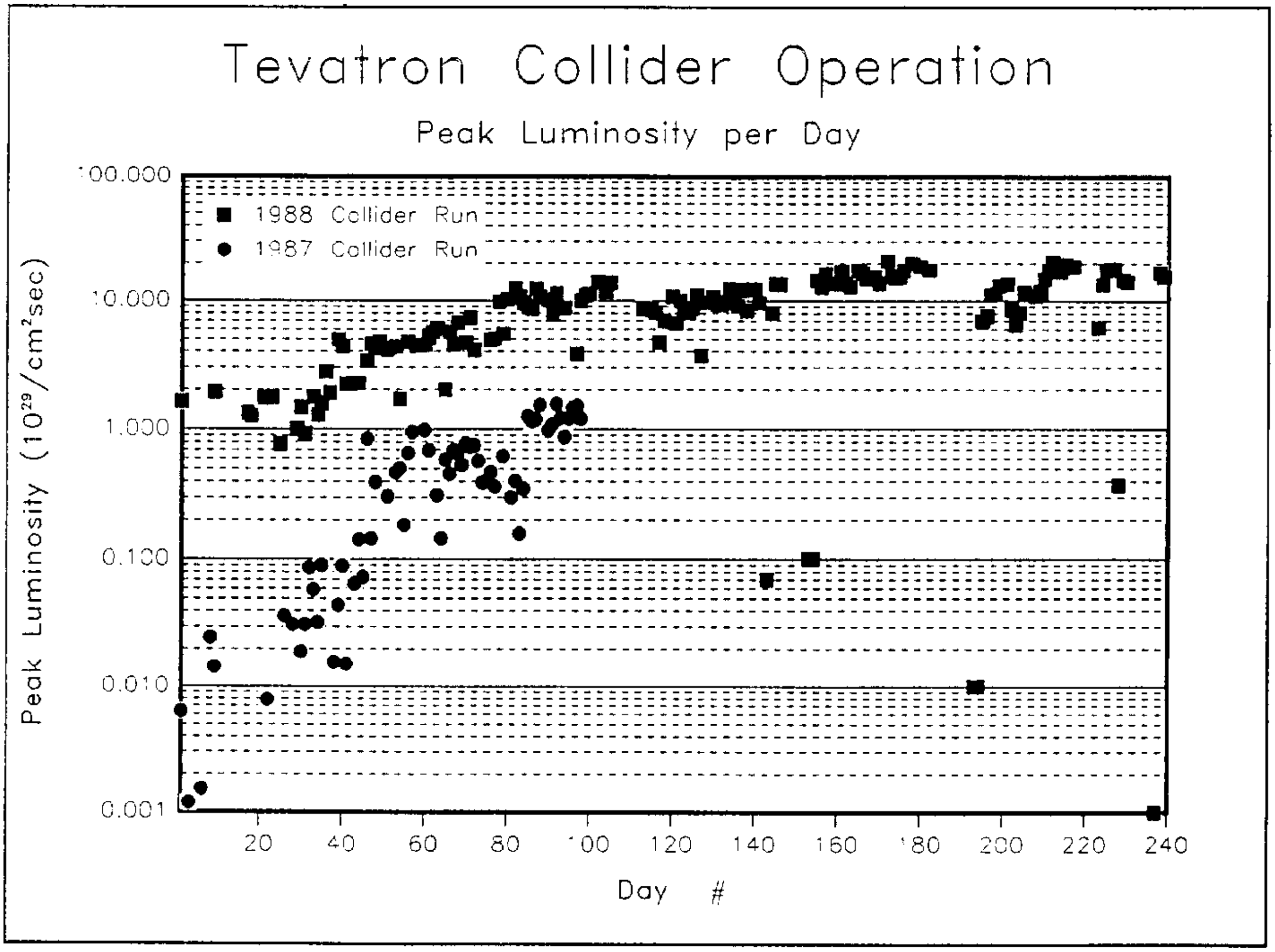

Fig. 12. Tevatron Collider peak luminosity for the 1987 and 1988 runs.
Design Luminosity is 10 x ($10^{29}/cm^2sec$)

3.2 CDF Results and Prospects

The first run of CDF took place in 1987 and resulted in an integrated luminosity of $33nb^{-1}$ recorded on tape. In spite of this rather modest number, **E-741** significant contributions to physics were made. Due to the highest center-of-mass energy yet achieved by man, CDF's first publication reported comparisons of charged particle multiplicity distributions and momentum spectra at $\sqrt{s} = 1800$ GeV with those at $\sqrt{s} = 630$ GeV (where there is data from CERN). However, more significant physics contributions were obtained in the study of the inclusive p_T spectrum of jets, where due to the higher energy, CDF was able to set new limits on quark compositeness. Studies of missing transverse energy, lead to new limits being set on the production of supersymmetric particles. Fifty times as much data has already been recorded during the 1988 run than was obtained in 1987. Before the present collider run ends the data sample should at least double.

During the 1987 CDF run, 50,000 events were collected at 1.8 TeV center–of–mass energy with a minimum bias trigger sensitive to 95% of the inelastic cross section. In addition, several thousand events were collected at a center-of-mass energy of 0.63 TeV. A number of interesting $\ln s$ physics results were obtained from this data. The single particle inclusive cross-sections for charged particles were published in Physical Review Letters for transverse momenta as large as 10 GeV/c and at both 1.8 and 0.63 TeV center–of–mass energies (see Fig. 13). Results on charged particle angular distributions at both energies have been prepared for publication. CDF finds an increase in $\frac{1}{N}\frac{dN}{d\eta}$ from 3.2 to 4.0 as the center-of-mass energy increases from 0.63 to 1.8 TeV. Results on KNO scaling, $< p_{\perp} >$ versus charged particle multiplicity, and charged particle correlations with high momenta tracks have been presented at conferences. Clean K° and Λ° signals have been observed and presented at conferences, and Physical Review Letters articles are in preparation.

From a subset of $25\,nb^{-1}$ of the data collected from the 1987 run, substantial QCD tests have already been performed and are being readied for publication. This sample is sufficient to probe possible quark substructure more deeply than can be done at S$\bar{p}$pS energies. In addition, the jet cross section is seen to be roughly a factor of 10 larger at the highest jet E_T seen by the UA1/UA2 experiments.

The inclusive jet cross section in the central rapidity region, $d\sigma(\bar{p}p \to \text{jet} + x)/dE_T$, as measured by CDF, is shown in Fig. 14 and is compared to a range of leading order QCD predictions. The data are well described by QCD and provide a sensitive test of possible quark compositeness, which can be parameterized by a four–body Fermi contact interaction between quarks with an energy scale, Λ_c, defining the coupling. The 1987 data allowed CDF to set a lower limit on Λ_c of 700 GeV (95% CL). This is to be compared to the equivalent limit at CERN of 415 GeV, derived with approximately 20 times the integrated luminosity.

The dominance of t-channel exchange in parton-parton scattering has been confirmed at Tevatron energies by examining the angular distribution of dijet events in the center-of-mass system. The data is shown in Fig. 15 for three different ranges of dijet invariant mass. It indicates a confirmation of the QCD at these energies, which predicts a Rutherford-like angular distribution.

Publications also in progress from 1987 data include analysis of direct photon production, test of jet fragmentation, global event measures, and tests of hard multiple parton collisions in a single $\bar{p}p$ collision. With approximately 100 times this data set, a thorough study of multijet processes is planned, in addition to precise QCD tests, and for compositeness at a still shorter distance scale.

The rate for events with large missing transverse energy was found to be consistent with that expected from purely conventional sources (heavy quark decays, W bosons decaying into τ's, and high p_T Z bosons decaying into neutrinos). The absence of an anomalous rate of missing E_T events allowed CDF to set stringent limits on the existence of supersymmetric partners of quarks and gluons, (*i.e.*, squarks and gluinos). At the 90% confidence level, the mass of the squark must be greater than 74 GeV, and the mass of the gluino must be greater than 73 GeV (see Fig. 16).

The 1988/89 run began in June of 1988. By February of 1989, about 6 pb^{-1} had been delivered and CDF had 2.5 pb^{-1} on tape. Some conclusions relevant to the future of the Tevatron Collider program may be inferred from a preliminary examination of this data. There will be very accurate tests of the Standard Model from the large sample of Ws (10000) and Zs (1000) with leptonic decay modes. Already there are some 2000 Ws and 250 Zs analyzed. Such a large sample will allow a comprehensive study of the systematic errors in both the measurement of the electron momentum by the tracking chambers and the measurement of electron energy in the EM calorimeters. This will result in a new level of precision for the W and Z masses and their difference, fundamental numbers for testing the Standard Model.

Similar statements can be made about testing QCD through studies of the jet structure of events with two or more jets. Unique probes of QCD will be made my studying events with a W, Z, or γ accompanied by jets. However the most exciting results will come from the search for "new physics." It is clear from the preliminary reduction of the data that there is a collection of rare events such as high mass Drell-Yan pairs, very high p_t jets, events with very high p_t photons, etc that will only be well understood by running with an integrated luminosity of 100 pb^{-1} or more.

In a sense we are several years "ahead of schedule" in that our goal for the next run should be 100 pb^{-1}, not 10 pb^{-1}. With the Upgrade, the detectors can handle such integrated luminosities and the machine can be made to deliver it. The physics requires it.

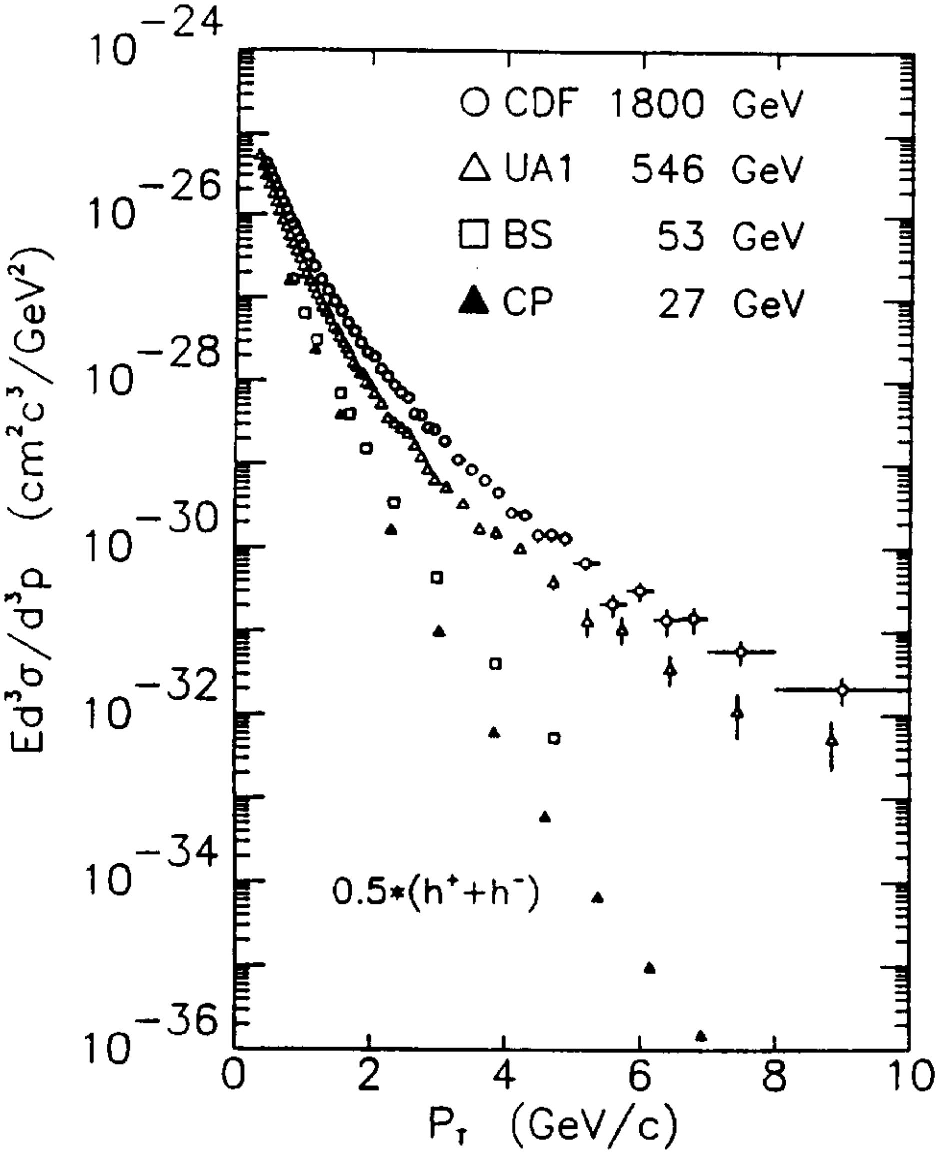

Fig. 13. Inclusive single particle invariant cross-section as a function of $p_\perp$ in collider experiments.

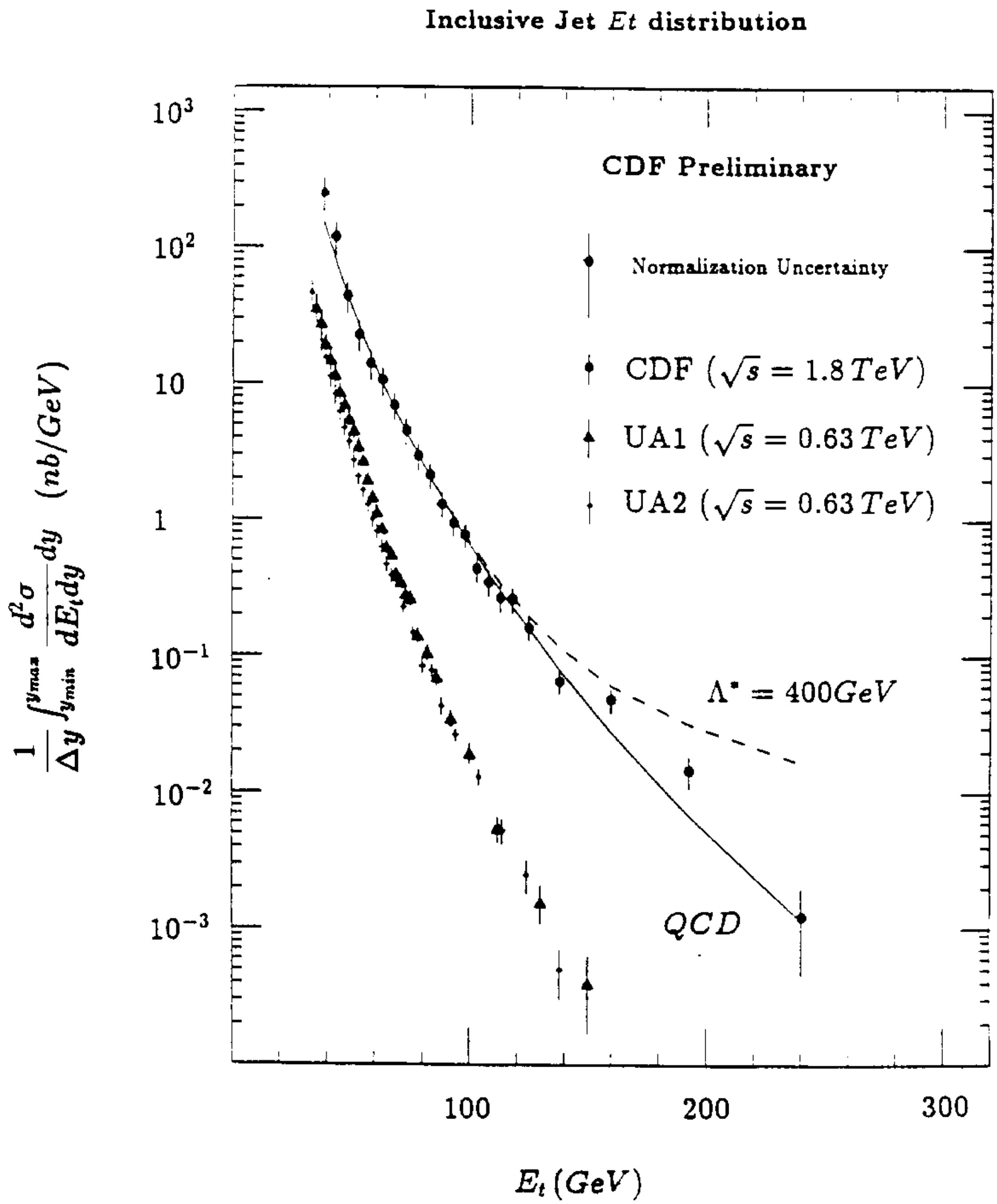

Fig. 14. Dijet cross-section data from the CERN $Sp\bar{p}S$ and the CDF experiment.

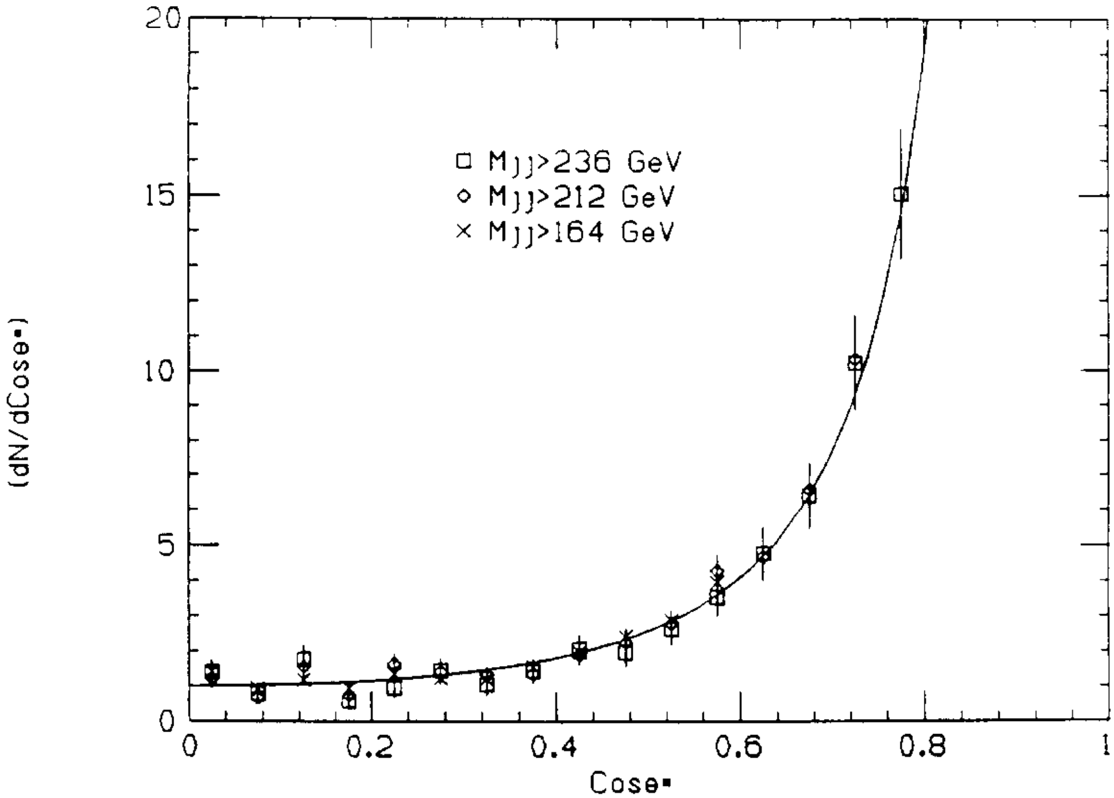

Fig. 15. CDF data on the dijet angular distribution compared to a Rutherford like distribution.

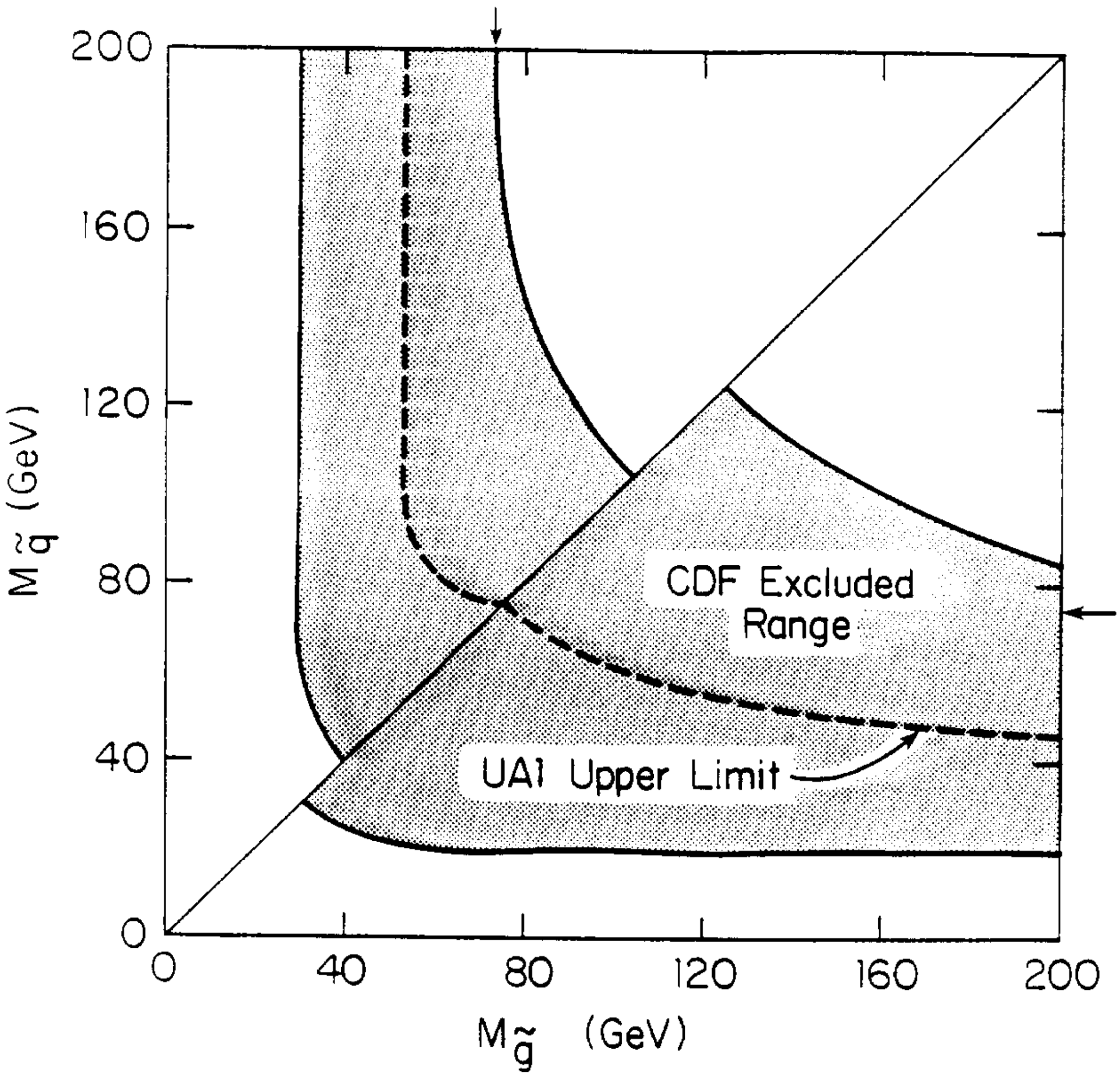

Fig. 16. CDF and UA1 limits on supersymmetric particle masses.

3.3 Small Collider Experiments

In addition to CDF, three small experiments, E-710, E-713, and E-735, have taken Collider data. These have in common the characteristic of exploring a physics "niche" – some particular physics question which a large, general purpose, detector is not ideally suited to study.

The goal of E-710 is to measure the proton-antiproton total cross section, the slope of the elastic scattering distribution, and ρ (the ratio of the real to imaginary part of the forward scattering amplitude) at energies from $\sqrt{s}$ = 300 to 1800 GeV. The experiment is located around the E0 $\bar{p}p$ interaction point. Detectors for measuring small-angle elastic scattering are drift chambers and scintillation counters housed in "Roman Pots," which can be placed very close to the circulating beams of the Tevatron. The experiment has reported a value for the elastic scattering logarithmic nuclear slope parameter, B, of 17.2 $\pm$ 1.3 $(GeV/c)^{-2}$ at $\sqrt{s} = 1800\ GeV$, which fits well on extrapolations from lower energy data. A value for the total cross-section at the same energy will be available very shortly. Measurements of ρ, which will help to resolve a puzzle generated by lower energy results, are currently being made. **E-710**

Whenever a previously unattainable energy range is opened up by operation of a new accelerator, it is an opportunity to look for hypothesized particles not previously observed at lower energy machines. One such particle, long the subject of theoretical discussion and experimental searches, is the magnetic monopole. E-713 undertook a search for this particle at D0 in the Tevatron Collider. Three types of track-etch detectors (glass, CR-39, and Rodyne polycarbonate) were placed around the D0 interaction region, and remained there throughout the Collider run. After the run ended, the detectors were removed, etched, and the tracks were studied. No monopoles were found, but E-713 already provides the best cross-section limits for a monopole mass greater than 20 GeV. Current running should push the limits a further factor of 20 lower. **E-713**

Experiment 735 is a search for evidence of a transition to quark-gluon plasma in hadronic matter. The transverse momentum spectrum of centrally produced particles in the $\bar{p}p$ collision is detected using a magnetic spectrometer (with particle identification), while the associated charged particle multiplicity is measured in a central tracking chamber and hodoscope, located **E-735** around the C0 interaction point. The experiment has produced its first data on the multiplicity dependence of the transverse momentum spectrum for centrally produced hadrons. These data raise the possibility of interesting structures in this dependence. Such structures could be interpreted as one of the signatures of a phase transition in hadronic matter. Data has also recently been published on the transverse momentum spectrum of lambdas produced in the central region. It is observed that the average transverse momentum increases more rapidly with c.m. energy than that of charged particles, and that the ratio of lambdas to charged particles increases with c.m. energy. These results are interesting because it is predicted that the formation of a quark-gluon plasma could result in enhanced hyperon production.

4 Advanced Computer Project

4.1 Experimental Physics Applications

High Energy Physics has been constrained for many years by available computing power. This fundamental problem has been addressed with the development of the Advanced Computer Program (ACP) at Fermilab. The ACP is conceptually a large "farm" of independent, inexpensive processors (nodes) with their own local memory and operating asynchronously in parallel, controlled by one central VAX computer, with a specialized operating system. Special emphasis has been placed upon user friendliness and accessibility, which is unique to the ACP as parallel computing systems, and an infinitely diverse set of applications are possible. 20 million event experiments were virtually inconceivable before ACP, while billion–event experiments, such as expected at the SSC, are now becoming thinkable. In addition to off–line computing and data analysis, the ACP is becoming a standard element for programmable on–line triggering.

As data in a typical experiment moves from digitizers to published results, extensive computing is required at each major step. The first ACP Multi–microprocessor system began operation in the Computing Center in July 1986. During the initial period the performance of the system nearly matched the Computer Center's large mainframes, while construction cost of the ACP was two orders of magnitude less. The system received the IR-100 Award by *Research and Development Magazine* as one of the 100 most significant technical developments of 1986, and at this writing is featured on the cover of the Jan./Feb. issue of *Computers in Physics.*

Triggering requirements are becoming increasingly severe (for SSC–scale experiments this will be a major technological challenge). The ACP system was designed to be able to accept extraordinarily high data rates (well over 100 megabytes/second) so that it can function in any foreseeable high level trigger. The CDF experiment, and the MEGA experiment of Los Alamos have chosen to incorporate the ACP into their FASTBUS data acquisition systems, this system having been tested at an impressive zero–error–rate for 48 hours at 20 megabytes/second.

To date, three experiments have published results from data analyzed on the ACP, E–400, E–691 and E–731. Nine experiments are presently analyzing data, with a total of about 40,000 data tapes. Present estimates for off–line computing are about 1500 VAX equivalents for each large experiment at the SSC. These needs can be readily met by the present developments in ACP Multiprocessors at a fraction of the cost of alternatives. A factor of five improvement in performance/cost is foreseeable with RISC processors in the next few years.

The ACP is a prime example of Fermilab's technology transfer to the public sector. Omnibyte Corp. of West Chicago, Ill., has delivered hundreds of ACP–designed CPU's, with a majority of orders placed outside of Fermilab.

4.2 Fermilab Lattice Gauge Project

QCD is *the* candidate theory of the strong interactions. It can be directly compared to experiment in certain very high energy regimes where only the dynamics at short–distance is relevant, but at low energies, where there exists a wealth of experimental data, the theory is intrinsically nonperturbative and mathematically unwieldy. Here we have the rich phenomena associated with quark confinement such as the various static properties, *e.g.*, masses, mixing angles, decay constants, magnetic moments, etc., of the hadrons, as well as exclusive decay modes, low p_T and diffractive physics, etc., which the theory must ultimately confront.

The lattice formulation of QCD allows one to compute, in principle, all aspects of the strong coupling phase by numerical methods. This effort has developed into a full–fledged subcommunity of theoretical physics and there have been preliminary successes. The key to solving the problem is to have access to the most advanced and powerful parallel architecture computing systems. Today, about a third of the Fermilab Theory group is devoted to Lattice Gauge Theory, using a new ACP Multi–Array Processor in collaboration with the ACP. This must be ranked as one of the leading special purpose Lattice Gauge Theory efforts operating now or in the foreseeable future.

A prototype system of 16 nodes is currently in operation at about 320 megaflops, while a full–scale 256–node machine will operate at 5 giga–flops. This places the ACP Lattice Gauge Theory effort in the forefront with other special purpose systems ultimately designed to operate between 1 and 16 gigaflops.

5 Theoretical Physics and Astrophysics

The Fermilab Theory Group has made major contributions to various branches of theoretical particle physics over the past decade and ranks, probably, in the top ten theory groups in the U.S. today.

The study of perturbative and lattice QCD (see Section 4.2) are large components of the program. The group has provided an important link between theory and experiment with a healthy program of QCD perturbative calculations, now focussed on heavy flavor photo– and hadro–production. An influential study of supercollider physics signatures has played an important role in conceptualizing future experiments at the SSC. J. D. Bjorken has played an extremely important role as both a theorist and as an Associate Director where he has been a key "Godfather" of many of the Fixed–Target experiments. Many of the theorists enjoy a fruitful dialogue with the Astrophysics Group and have worked on a variety of problems ranging from Solar Neutrino Oscillations (MSW effect) to formal studies of Inflationary Quantum Field Theory. Several members of the group have been leaders in the developments of the more formal aspects of theoretical physics during the decade.

During the past decade the Fermilab Theory Group has roughly doubled in permanent staff and post–docs. It maintains a very active community of "users" and visitors and has hosted numerous workshops and large conferences.

Fermilab is unique amongst High Energy Physics Laboratories in having a theoretical group especially devoted to the interplay between particle physics and cosmology. This group has been partially funded by NASA and overlaps strongly with the activities of the Fermilab Theory Group.

The Astrophysics Group has been a world center for the study of Cosmic Strings, a candidate mechanism for the seeding of structure formation in the early Universe, and has hosted Inner Space/Outer Space and the first Quantum Cosmology Workshop representing the development of that new field of research which the group is actively pursuing. It is also been active in the theoretical study of Inflationary scenarios and Dark–Matter, which is playing an increasingly important role in experimental physics.

6 The Fermilab Upgrade

Fermilab now has a research program poised to fully exploit the Tevatron, both in Collider and Fixed-Target modes. In order to provide the tools to accomplish that goal, a plan has been made, as outlined in "The Fermilab Upgrade — An Overview", January 7, 1989. Implementation of this plan would serve to insure that the subsequent edition of this report, for the years 1988 to 1998, would be studded with major new research results from a program of great depth and vitality. The physics opportunities of the next decade at Fermilab dictate the Upgrade.

APPENDIX

Fermi National Accelerator Laboratory
Index of Experiments by Proposal Status as of Mar 8, 1989

APPROVED PROPOSALS (383)

Total number of proposals - 804

Approved proposals - 383

Experiment		*Spokesperson(s)*	*Run Status*	*as of date*
1A	NEUTRINO #1A	David B. Cline	Completed	Jun 30, 1975
2B	30-INCH HYBRID #2B	Gerald A. Smith	Completed	Apr 22, 1974
3	MONOPOLE #3	Philippe Eberhard	Completed	Sep 4, 1974
4	NEUTRON CROSS SECTION #4	Michael J. Longo	Completed	Mar 20, 1974
7	ELASTIC SCATTERING #7	Donald I. Meyer	Completed	Jan 28, 1975
8	NEUTRAL HYPERON #8	Lee G. Pondrom	Completed	Mar 22, 1976
12	NEUTRON BACKWARD SCATTERING #12	Neville W. Reay	Completed	Dec 2, 1974
14A	PROTON-PROTON INELASTIC #14A	Paolo Franzini	Completed	Jun 21, 1973
21A	NEUTRINO #21A	Barry C. Barish	Completed	Nov 2, 1975
22	MULTIGAMMA #22	George B. Collins	Completed	Jun 26, 1974
25A	PHOTON TOTAL CROSS SECTION #25A	David O. Caldwell	Completed	Nov 30, 1976
26	MUON #26	Louis N. Hand	Completed	Apr 16, 1974
27A	NEUTRON DISSOCIATION #27A	Jerome L. Rosen	Completed	Apr 24, 1974
28A	15-FOOT NEUTRINO/H2&NE #28A	William F. Fry	Completed	Jun 11, 1975
31A	15-FOOT ANTI-NEUTRINO/H2 #31A	Malcolm Derrick	Completed	Aug 13, 1977
34	DETECTOR DEVELOPMENT #34	Richard W. Huggett	Completed	Jun 26, 1974
36A	PROTON-PROTON SCATTERING #36A	Rodney L. Cool	Completed	Jun 24, 1973
37A	30-INCH P-P @ 300 #37A	Ernest I. Malamud	Completed	Jun 1, 1973
45A	15-FOOT NEUTRINO/H2 #45A	Frank A. Nezrick	Completed	Jan 13, 1976
48	MUON SEARCH #48	Robert K. Adair	Completed	Dec 1, 1975
51A	MISSING MASS #51A	Eberhard Von Goeler	Completed	Oct 23, 1974
53A	15-FOOT NEUTRINO/H2&NE #53A	Charles Baltay	Completed	Mar 9, 1981
61	POLARIZED SCATTERING #61	Owen Chamberlain	Completed	Oct 26, 1977
63A	PHOTON SEARCH #63A	James K. Walker	Completed	Mar 13, 1975
67A	PROTON-PROTON MISSING MASS #67A	Felix Sannes	Completed	Aug 8, 1973
69A	ELASTIC SCATTERING #69A	Joseph Lach	Completed	Mar 3, 1976
70	LEPTON #70	Leon M. Lederman	Completed	Dec 1, 1974
72	QUARK #72	Lawrence B. Leipuner	Completed	Jun 11, 1973
75	QUARK #75	Taiji Yamanouchi	Completed	Sep 8, 1973
76	MONOPOLE #76	Richard A. Carrigan	Completed	Dec 1, 1974
81A	NUCLEAR CHEMISTRY #81A	Sheldon Kaufman	Completed	Oct 1, 1978
82	K ZERO REGENERATION #82	Valentine L. Telegdi	Completed	Jul 5, 1975
86A	PION DISSOCIATION #86A	Henry J. Lubatti	Completed	Mar 22, 1976
87A	PHOTOPRODUCTION #87A	Thomas Ohalloran	Completed	May 7, 1978
90	EMULSION/PROTONS @ 200 #90	Wladyslaw Wolter	Completed	Sep 20, 1972
95A	PHOTON SEARCH #95A	Bradley B. Cox	Completed	Oct 17, 1977
96	ELASTIC SCATTERING #96	David Ritson	Completed	Feb 17, 1975
98	MUON #98	Herbert L. Anderson	Completed	Feb 17, 1975
99	ASSOCIATED PRODUCTION #99	Robert E. Diebold	Completed	Jan 24, 1978
100A	PARTICLE SEARCH #100A	Pierre A. Piroue	Completed	Apr 4, 1974
103	EMULSION/PROTONS @ 200 #103	David T. King	Completed	Sep 20, 1972
104	TOTAL CROSS SECTION #104	Thaddeus F. Kycia	Completed	Dec 22, 1977
105	EMULSION/PROTONS @ 200 #105	Prince K. Malhotra	Completed	Sep 20, 1972
108	BEAM DUMP #108	Miguel Awschalom	Completed	Jun 2, 1975
110A	MULTIPARTICLE #110A	Alexander R. Dzierba	Completed	Apr 9, 1978
111	PION CHARGE EXCHANGE #111	Alvin V. Tollestrup	Completed	Sep 19, 1974
114	EMULSION/PROTONS @ 200 #114	Piyare L. Jain	Completed	Sep 20, 1972
115	LONG-LIVED PARTICLES #115	M. Lynn Stevenson	Completed	Nov 23, 1974
116	EMULSION/PROTONS @ 200 #116	Jacques D. Hebert	Completed	Sep 20, 1972
117A	EMULSION/PROTONS @ 200 #117A	Osamu Kusumoto	Completed	Sep 20, 1972
118A	INCLUSIVE SCATTERING #118A	George W. Brandenburg	Completed	Jul 20, 1977
120	PHOTON SEARCH #120	David B. Cline	Completed	May 29, 1973
121A	30-INCH PI+ & P - P @ 100 #121A	Richard L. Lander	Completed	Jan 23, 1974
125	30-INCH PI- - P @ 100 #125	Douglas R. O. Morrison	Completed	Aug 28, 1973
137	30-INCH PI- - P @ 200 #137	Fred Russ Huson	Completed	Mar 10, 1973
138	30-INCH P-P @ 400 #138	Jack C. Vander Velde	Completed	Aug 26, 1975
141A	30-INCH P-P @ 200 #141A	Thomas H. Fields	Completed	Nov 27, 1972
142	SUPER-HEAVY ELEMENTS #142	Raymond W. Stoughton	Completed	Jun 4, 1975
143A	30-INCH PI- - P @ 300 #143A	George R. Kalbfleisch	Completed	Apr 10, 1974
147	SUPER-HEAVY ELEMENTS #147	Monique Debeauvais	Completed	Jun 11, 1975
152B	PHOTOPRODUCTION #152B	Clemens A. Heusch	Completed	Nov 13, 1978
154	30-INCH HYBRID #154	Irwin A. Pless	Completed	Mar 13, 1974
155	15-FOOT EMI TEST #155	Vincent Z. Peterson	Completed	Nov 30, 1974
156	EMULSION/PROTONS @ 200 #156	Kiyoshi Niu	Completed	Sep 20, 1972
161	30-INCH P - P&NE @ 300 #161	James Mapp	Completed	Jun 25, 1974
163A	30-INCH PI- - P&NE @ 200 #163A	William D. Walker	Completed	Jun 18, 1974
171	EMULSION/PROTONS @ 200 #171	Jere J. Lord	Completed	Sep 20, 1972
172	15-FOOT ANTI-NEUTRINO/H2&NE#172	Henry J. Lubatti	Completed	May 25, 1976
177A	PROTON-PROTON ELASTIC #177A	Jay Orear	Completed	Apr 19, 1977
178	MULTIPLICITIES #178	Wit Busza	Completed	Aug 14, 1975
180	15-FOOT ANTI-NEUTRINO/H2&NE#180	Pavel F. Ermolov	Approved/Inactive	Feb 14, 1984
181	EMULSION/PROTONS @ 300 #181	Arthur S. Cary	Completed	Oct 20, 1973
183	EMULSION/PROTONS @ 200 #183	M. I. Tretjakova	Completed	Sep 20, 1972
184	PARTICLE SEARCH #184	Peter J. Wanderer	Completed	May 29, 1974
186	PROTON-DEUTERON SCATTERING #186	Adrian Melissinos	Completed	Aug 19, 1974
187	PARTICLE SEARCH #187	Leon M. Lederman	Completed	Nov 6, 1973
188	PROTON-NUCLEON INCLUSIVE #188	Felix Sannes	Completed	May 9, 1973
189	EMULSION/PROTONS @ 200 #189	David Ritson	Completed	Sep 20, 1972
194	30-INCH P - D @ 100 #194	C. Thornton Murphy	Completed	Aug 20, 1976
195	EMULSION/PROTONS @ 300 #195	Yu K. Lim	Completed	Jun 10, 1975
196	30-INCH P - D @ 400 #196	Roderich J. Engelmann	Completed	Oct 20, 1975
198A	PROTON-NUCLEON SCATTERING #198A	Stephen L. Olsen	Completed	Apr 19, 1977

APPROVED PROPOSALS *(continued)*

Experiment		Spokesperson(s)	Run Status	as of date
199	MASSIVE PARTICLE SEARCH #199	Sherman Frankel	Completed	Aug 22, 1973
202	TACHYON MONOPOLE #202	David F. Bartlett	Completed	May 19, 1976
203A	MUON #203A	Leroy T. Kerth	Completed	May 18, 1978
205A	EMULSION/MUONS @ 150 #205A	Osamu Kusumoto	Completed	Oct 16, 1973
209	30-INCH P - D @ 300 #209	Fu Tak Dao	Completed	Oct 7, 1975
211	BEAM DUMP #211	Klaus Goebel	Completed	Nov 14, 1973
216	FORM FACTOR #216	Donald H. Stork	Completed	Oct 1, 1975
217	30-INCH PI+ & P - P @ 200 #217	Richard L. Lander	Completed	May 15, 1974
218	30-INCH PI- - D @ 200 #218	Philip M. Yager	Completed	Sep 18, 1974
221	PROTON-PROTON INELASTIC #221	Paolo Franzini	Completed	Sep 5, 1974
226	K ZERO CHARGE RADIUS #226	Valentine L. Telegdi	Completed	Mar 17, 1977
228	30-INCH PI+ & P - P @ 60 #228	Thomas Ferbel	Completed	Apr 15, 1974
229	DETECTOR DEVELOPMENT #229	Luke C. L. Yuan	Completed	Nov 16, 1974
230	MULTIGAMMA #230	Michael J. Longo	Completed	Apr 24, 1974
232	EMULSION/PROTONS @ 300 #232	David T. King	Completed	Oct 20, 1973
233	EMULSION/PROTONS @ 300 #233	Jacques D. Hebert	Completed	Oct 20, 1973
234	15-FOOT ENGINEERING RUN #234	Fred Russ Huson	Completed	Nov 5, 1974
236A	HADRON JETS #236A	Paul M. Mockett	Completed	Jul 20, 1977
237	EMULSION/PROTONS @ 300 #237	Jere J. Lord	Completed	Jun 10, 1975
238	EMULSION/PROTONS @ 400 #238	Jere J. Lord	Completed	Dec 9, 1975
239	LONG-LIVED PARTICLES #239	William Frati	Completed	Feb 3, 1974
242	EMULSION/PROTONS @ 300 #242	Kiyoshi Niu	Completed	Oct 20, 1973
243	EMULSION/PROTONS @ 400 #243	Kiyoshi Niu	Completed	Dec 9, 1975
244	EMULSION/PROTONS @ 300 #244	Piyare L. Jain	Completed	Oct 20, 1973
245	EMULSION/PROTONS @ 400 #245	Piyare L. Jain	Completed	Dec 9, 1975
247	PARTICLE SEARCH #247	Eric H. S. Burhop	Completed	May 18, 1976
248	NEUTRON ELASTIC SCATTERING #248	Michael J. Longo	Completed	Dec 10, 1976
249	EMULSION/PROTONS @ 400 #249	Wladyslaw Wolter	Completed	Dec 9, 1975
250	EMULSION/PROTONS @ 300 #250	Osamu Kusumoto	Completed	Oct 20, 1973
251	EMULSION/PROTONS @ 400 #251	Osamu Kusumoto	Completed	Dec 9, 1975
252	30-INCH P-P @ 100 #252	Thomas Ferbel	Completed	Dec 6, 1972
253	NEUTRINO #253	Luke W. Mo	Completed	Mar 7, 1979
254	NEUTRINO #254	George R. Kalbfleisch	Completed	Oct 15, 1975
255	EMULSION/MUONS @ 150 #255	Piyare L. Jain	Completed	Oct 16, 1973
258	PION INCLUSIVE #258	Melvyn J. Shochet	Completed	Jul 9, 1979
260	HADRON JETS #260	Donald W. Mcleod	Completed	Sep 20, 1976
261	DETECTOR DEVELOPMENT #261	Ching Lin Wang	Completed	Nov 20, 1974
262	NEUTRINO #262	Barry C. Barish	Completed	Mar 20, 1974
264	EMULSION/PI- @ 200 #264	Poh Shien Young	Completed	Oct 7, 1974
265	EMULSION/PROTONS @ 400 #265	Poh Shien Young	Completed	Dec 9, 1975
268	INCLUSIVE PHOTON #268	Joel Mellema	Completed	Feb 11, 1976
271	EMULSION/PROTONS @ 200 #271	Kurt Gottfried	Completed	Jun 10, 1975
272	HADRON DISSOCIATION #272	Thomas Ferbel	Completed	Dec 3, 1979
275	PLASTIC DETECTORS #275	Wolfgang Enge	Completed	Oct 20, 1973
276	QUARK #276	Andreas Van Ginneken	Completed	Nov 2, 1975
279	EMULSION/PROTONS @ 400 #279	David T. King	Completed	Dec 9, 1975
280	30-INCH P - D @ 200 #280	Thomas H. Fields	Completed	Oct 11, 1975
281	30-INCH HYBRID #281	Gerald A. Smith	Completed	Sep 28, 1975
284	PARTICLE PRODUCTION #284	James K. Walker	Completed	Oct 3, 1976
285	SUPER-HEAVY ELEMENTS #285	Leon M. Lederman	Completed	Aug 2, 1976
288	DI-LEPTON #288	Leon M. Lederman	Completed	Jul 23, 1978
289	PROTON-HELIUM SCATTERING #289	Ernest I. Malamud	Completed	Nov 8, 1977
290	BACKWARD SCATTERING #290	Winslow F. Baker	Completed	Jul 31, 1978
292	EMULSION/PROTONS @ 400 #292	Kurt Gottfried	Completed	Dec 9, 1975
295	30-INCH PI+ & P - D @ 200 #295	Gideon Yekutieli	Completed	Nov 2, 1975
297	QUARK #297	Lawrence B. Leipuner	Completed	Jul 10, 1974
299	30-INCH HYBRID #299	Irwin A. Pless	Completed	Nov 22, 1976
300	PARTICLE SEARCH #300	Pierre A. Piroue	Completed	Apr 24, 1976
305	NEUTRON DISSOCIATION #305	Bruno Gobbi	Completed	Apr 14, 1975
310	NEUTRINO #310	David B. Cline	Completed	Aug 31, 1978
311	30-INCH PBAR - P @ 100 #311	William W. Neale	Completed	Jan 27, 1975
313	PROTON-PROTON POLARIZATION #313	Homer A. Neal	Completed	Mar 30, 1977
317	PROTON-NUCLEON INELASTIC #317	Rodney L. Cool	Completed	Nov 1, 1975
319	MUON #319	K. Wendell Chen	Completed	Sep 20, 1976
320	NEUTRINO #320	Frank Sciulli	Completed	Oct 1, 1974
321	PROTON-PROTON INELASTIC #321	Juliet Lee-Franzini	Completed	Sep 20, 1976
324	INCLUSIVE SCATTERING #324	Howard L. Weisberg	Completed	Aug 13, 1977
325	PARTICLE SEARCH #325	Pierre A. Piroue	Completed	Feb 28, 1977
326	DI-MUON #326	Melvyn J. Shochet	Completed	Apr 26, 1982
327	DETECTOR DEVELOPMENT #327	Wade W. M. Allison	Completed	Feb 7, 1975
328	EMULSION/PI- @ 200 #328	M. I. Tretjakova	Completed	Oct 7, 1974
329	EMULSION/PROTONS @ 300 #329	M. I. Tretjakova	Completed	Jun 10, 1975
330	PARTICLE SEARCH #330	Richard Gustafson	Completed	Jul 7, 1975
331	DI-MUON #331	James E. Pilcher	Completed	Mar 22, 1976
335	MUON SEARCH #335	Orrin D. Fackler	Completed	Jun 6, 1975
336	EMULSION/PROTONS @ 400 #336	Takeshi Ogata	Completed	Dec 9, 1975
337	DI-MUON #337	David P. Eartly	Completed	Feb 7, 1975
338	30-INCH PI- - D @ 360 #338	Keihachiro Moriyasu	Completed	Aug 28, 1976
339	EMULSION/PI- @ 200 #339	Wladyslaw Wolter	Completed	Jun 9, 1975
340	EMULSION/ELECTRONS @ HI E #340	Shoji Dake	Completed	Oct 5, 1976
341	15-FOOT P - P @ 400 #341	Winston Ko	Completed	Dec 21, 1975
343	15-FOOT P - P @ 300 #343	Roderich J. Engelmann	Completed	Jan 13, 1976
344	30-INCH PBAR - P @ 50 #344	Laszlo J. Gutay	Completed	Nov 1, 1976
345	30-INCH PBAR - D @ 100 #345	Gosta Ekspong	Completed	Sep 7, 1976
346	EMULSION/PROTONS @ 400 #346	Gosta Ekspong	Completed	Dec 9, 1975

APPROVED PROPOSALS *(continued)*

Experiment		Spokesperson(s)	Run Status	as of date
350	INCLUSIVE NEUTRAL MESON #350	Robert W. Kenney	Completed	Feb 24, 1977
356	NEUTRINO #356	Frank Sciulli	Completed	Jan 17, 1979
357	PARTICLE SEARCH #357	Donald I. Meyer	Completed	Jun 7, 1976
358	DI-MUON #358	Wonyong Lee	Completed	Oct 1, 1975
361	LAMBDA BETA-DECAY #361	Lee G. Pondrom	Completed	Oct 29, 1979
362	EMULSION/PI- @ 200 #362	Piyare L. Jain	Completed	Jun 9, 1975
363	PARTICLE SEARCH #363	Stephen L. Olsen	Completed	Apr 9, 1975
365	PARTICLE SEARCH #365	David A. Garelick	Completed	Feb 5, 1975
366	PARTICLE SEARCH #366	Maris A. Abolins	Completed	Jul 2, 1976
369	PARTICLE SEARCH #369	Thomas B. W. Kirk	Completed	Aug 13, 1977
370	NEUTRINO #370	David B. Cline	Completed	Mar 19, 1975
371	SUPER-HEAVY ELEMENTS #371	Mira Juric	Completed	Dec 20, 1975
373	EMULSION/MUONS @ 200 #373	Piyare L. Jain	Completed	Nov 22, 1976
374	EMULSION/PROTONS @ 300 #374	D. H. Davis	Completed	Jun 10, 1975
379	PARTICLE SEARCH #379	Stanley G. Wojcicki	Completed	Jun 8, 1977
380	15-FOOT NEUTRINO/H2&NE #380	Charles Baltay	Completed	Oct 31, 1979
381	PROTON-NUCLEON SCATTERING #381	Ernest I. Malamud	Completed	Mar 30, 1977
382	PARTICLE SEARCH #382	Louis N. Hand	Completed	Dec 19, 1975
383	INCLUSIVE K-SHORT #383	Hans G. E. Kobrak	Completed	May 7, 1978
385	EMULSION/PROTONS @ 400 #385	Yog Prakash	Completed	Dec 9, 1975
386	EMULSION/NEW PARTICLES #386	Jere J. Lord	Completed	Dec 29, 1976
387	EMULSION/PI- @ 200 #387	Richard J. Wilkes	Completed	Jun 9, 1975
388	15-FOOT ANTI-NEUTRINO/H2&NE#388	Vincent Z. Peterson	Completed	Sep 12, 1979
390	15-FOOT ANTI-NEUTRINO/D2 #390	Arthur F. Garfinkel	Approved/Inactive	Oct 26, 1981
391	MUON #391	Leroy T. Kerth	Completed	May 18, 1978
395	HADRON JETS #395	Walter Selove	Completed	Nov 16, 1977
396	HADRON DISSOCIATION #396	Konstantin Goulianos	Completed	Nov 23, 1977
397	PARTICLE SEARCH #397	Jerome L. Rosen	Completed	Aug 18, 1976
398	MUON #398	Richard Wilson	Completed	Dec 1, 1976
399	EMULSION/ELECTRONS @ > 100 #399	Robert L. Golden	Completed	Oct 5, 1976
400	PARTICLE SEARCH #400	James E. Wiss	Completed	Jun 24, 1984
401	PHOTOPRODUCTION #401	Michael F. Gormley	Completed	Nov 26, 1979
404	INCLUSIVE NEUTRON #404	Richard Gustafson	Completed	Jul 5, 1977
415	PARTICLE PRODUCTION #415	Lee G. Pondrom	Completed	Oct 18, 1976
416	PARTICLE SEARCH #416	Henry J. Lubatti	Completed	Jul 1, 1975
418	PARTICLE PRODUCTION #418	Felix Sannes	Completed	Oct 22, 1975
419	EMULSION/PROTONS @ 300 #419	Giorgio Giacomelli	Completed	Jun 10, 1975
421	EMULSION/PROTONS @ 300 #421	Venedict P. Dzhelepov	Completed	Jun 24, 1975
423	EMULSION/PROTONS @ 400 #423	Hisahiko Sugimoto	Completed	Dec 9, 1975
424	EMULSION/MUONS @ 200 #424	Tomonori Wada	Completed	Oct 8, 1976
425	K ZERO REGENERATION #425	Valentine L. Telegdi	Completed	May 17, 1976
426	FRAGMENTATION PARTICLES #426	Katsura Fukui	Completed	Mar 20, 1976
427	DETECTOR DEVELOPMENT #427	Luke C. L. Yuan	Completed	Jan 10, 1978
428	EMULSION/PROTONS @ 400 #428	Jacques D. Hebert	Completed	Dec 9, 1975
434	EMULSION/PROTONS @ 400 #434	Shoji Dake	Completed	Dec 9, 1975
435	MUON SEARCH #435	Robert K. Adair	Completed	Jul 2, 1976
436	DI-MUON #436	Robert K. Adair	Completed	Oct 29, 1975
438	NEUTRON-NUCLEUS INELASTIC #438	Lawrence W. Jones	Completed	Apr 18, 1977
439	MULTI-MUON #439	David A. Garelick	Completed	May 19, 1978
440	LAMBDA MAGNETIC MOMENT #440	Gerry M. Bunce	Completed	Mar 22, 1977
441	LAMBDA POLARIZATION #441	Lee G. Pondrom	Completed	Jul 2, 1977
442	NUCLEAR FRAGMENTS #442	Frank Turkot	Completed	Aug 13, 1977
444	DI-MUON #444	A. J. Stewart Smith	Completed	Jan 3, 1978
448	MUON #448	William A. Loomis	Completed	May 7, 1978
451	INCLUSIVE SCATTERING #451	Donald S. Barton	Completed	Sep 6, 1978
456	FORM FACTOR #456	Donald H. Stork	Completed	Apr 13, 1977
458	PHOTOPRODUCTION #458	Wonyong Lee	Approved/Inactive	Oct 27, 1981
461	EMULSION/PROTONS @ 400 #461	Jere J. Lord	Completed	Dec 9, 1975
462	EMULSION/PROTONS @ 400 #462	Giorgio Giacomelli	Completed	Dec 9, 1975
463	EMULSION/PROTONS @ 400 #463	M. I. Tretjakova	Completed	Dec 9, 1975
466	NUCLEAR FRAGMENTS #466	Norbert T. Porile	In Progress	Jul 1, 1981
467	TEST MUON IRRADIATION #467	Melvin Freedman	Completed	Dec 1, 1976
468	PARTICLE SEARCH #468	Phillip H. Steinberg	Completed	Aug 14, 1977
469	PARTICLE SEARCH #469	David Cutts	Completed	May 15, 1978
472	PARTICLE SEARCH #472	Kenneth C. Stanfield	Completed	Nov 29, 1976
481	EMULSION/PI- @ 300 #481	Yoshiyuki Takahashi	Completed	Jan 18, 1978
482	NEUTRINO #482	Barry C. Barish	Completed	Jan 3, 1978
486	K ZERO CROSS SECTION #486	Bruce D. Winstein	Completed	Mar 17, 1977
490	PARTICLE SEARCH #490	Jack Sandweiss	Completed	Jun 9, 1980
494	DI-HADRON #494	Myron L. Good	Completed	Feb 21, 1977
495	XI-ZERO PRODUCTION #495	Kenneth J. Heller	Completed	Aug 28, 1978
497	CHARGED HYPERON #497	Joseph Lach	Completed	Mar 16, 1981
498	DETECTOR DEVELOPMENT #498	Charles R. Gruhn	Completed	Aug 18, 1976
499	EMULSION/PROTONS @ 400 #499	Junsuke Iwai	Completed	Jan 15, 1978
501	TEST MUON IRRADIATION #501	Kenneth Lande	Completed	Dec 1, 1976
502	MONOPOLE #502	David F. Bartlett	Completed	Jun 23, 1980
503	EMULSION/PI- @ 300 #503	Takeshi Ogata	Completed	Jan 18, 1978
505	PROTON POLARIZATION #505	Samuel Peter Yamin	Completed	Aug 27, 1978
506	EMULSION/PI- @ 300 #506	Shoji Dake	Completed	Jan 15, 1978
507	HIGH ENERGY CHANNELING #507	Edouard N. Tsyganov	Completed	May 30, 1977
508	EMULSION/PROTONS @ 500 #508	Wladyslaw Wolter	Completed	Apr 26, 1985
509	EMULSION/MUONS @ 200 #509	T. Shirai	Completed	Oct 8, 1976
510	EMULSION/ELECTRONS @ HI E #510	Kiyoshi Niu	Completed	Oct 5, 1976
515	PARTICLE SEARCH #515	Jerome L. Rosen	Completed	Mar 10, 1982
516	PHOTOPRODUCTION #516	E. Thomas Nash	Completed	Jun 1, 1981

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Experiment		*Spokesperson(s)*	*Run Status*	*as of date*
522	PROTON POLARIZATION #522	Harold O. Ogren	Completed	Mar 21, 1978
524	EMULSION/PROTONS > 500 GEV #524	Richard J. Wilkes	Completed	Apr 26, 1985
525	EMULSION/PI- @ 300 #525	Richard J. Wilkes	Completed	Jan 15, 1978
531	NEUTRINO #531	Neville W. Reay	Completed	Jun 1, 1981
533	PI-MU ATOMS #533	Gordon B. Thomson	Completed	Nov 28, 1979
536	EMULSION/NEUTRINO #536	Kiyoshi Niu	Completed	Aug 13, 1977
537	DI-MUON #537	Bradley B. Cox	Completed	Feb 28, 1982
540	PARTICLE SEARCH #540	Michael J. Longo	Completed	Feb 21, 1978
545	15-FOOT NEUTRINO/D2&HIZ #545	George A. Snow	Completed	Jan 17, 1979
546	15-FOOT NEUTRINO/H2&NE #546	Fred Russ Huson	Completed	Jan 26, 1978
547	EMULSION/PROTONS @ 400 #547	C. J. Jacquot	Completed	Jan 15, 1978
549	QUARK #549	Michael J. Longo	Approved/Inactive	Oct 26, 1981
552	P-N SCATTERING #552	Felix Sannes	Completed	Apr 9, 1978
553	NEUTRINO #553	Paul F. Shepard	Completed	Apr 1, 1980
555	NEUTRAL HYPERON #555	Thomas J. Devlin	Completed	Feb 17, 1982
557	HADRON JETS #557	Ernest I. Malamud	Completed	Aug 14, 1984
564	15-FOOT & EMULSION/NEUTRINO#564	Louis Voyvodic	Completed	Mar 9, 1981
565	30-INCH HYBRID #565	Irwin A. Pless	Completed	Jun 1, 1982
567	PARTICLE SEARCH #567	Michael S. Witherell	Completed	Nov 7, 1979
568	EMULSION/PI- @ 300 #568	Jacques D. Hebert	Completed	Jan 15, 1978
570	30-INCH HYBRID #570	Irwin A. Pless	Completed	Jun 1, 1982
573	EMULSION/PI- @ 300 #573	Noriyuki Ushida	Completed	Jan 15, 1978
574	EMULSION/PI- @ 300 #574	Wladyslaw Wolter	Completed	Jan 18, 1978
575	EMULSION/PROTONS @ 400 #575	Jere J. Lord	Completed	Jan 15, 1978
576	EMULSION/PROTONS @ 500 #576	Jacques D. Hebert	Completed	Jul 3, 1985
577	ELASTIC SCATTERING #577	Roy Rubinstein	Completed	Mar 16, 1981
580	PARTICLE SEARCH #580	Daniel R. Green	Completed	Jun 1, 1981
581	POLARIZED SCATTERING #581	Akihiko Yokosawa	Approved/Inactive	Feb 10, 1984
584	PARTICLE SEARCH #584	Bruce D. Winstein	Completed	Jan 22, 1980
585	KAON CHARGE EXCHANGE #585	William R. Francis	Completed	Mar 16, 1981
591	PARTICLE SEARCH #591	Laszlo J. Gutay	Completed	Feb 8, 1981
592	NUCLEAR SCALING #592	Sherman Frankel	Completed	Jul 17, 1978
594	NEUTRINO #594	James K. Walker	Completed	Jun 14, 1982
595	PARTICLE SEARCH #595	Arie Bodek	Completed	Jun 16, 1980
596	PARTICLE SEARCH #596	Leon M. Lederman	Completed	May 21, 1978
597	30-INCH HYBRID #597	J. James Whitmore	Completed	May 3, 1982
605	HIGH MASS PAIRS #605	John P. Rutherfoord	Completed	Aug 29, 1985
608	PARTICLE SEARCH #608	Charles N. Brown	Completed	Mar 7, 1979
609	HADRON JETS #609	Walter Selove	Completed	Feb 14, 1984
610	PARTICLE SEARCH #610	Thomas B. W. Kirk	Completed	Jun 23, 1980
612	PHOTON DISSOCIATION #612	Konstantin Goulianos	Completed	Apr 12, 1982
613	BEAM DUMP #613	Byron P. Roe	Completed	May 13, 1982
615	FORWARD SEARCH #615	Kirk T. Mcdonald	Completed	Jul 14, 1984
616	NEUTRINO #616	Frank Sciulli	Completed	Jan 22, 1980
617	CP VIOLATION #617	Bruce D. Winstein	Completed	Jun 14, 1982
619	TRANSITION MAGNETIC MOMENT #619	Thomas J. Devlin	Completed	Jun 14, 1982
620	CHARGED HYPERON MAG MOMENT #620	Lee G. Pondrom	Completed	Jan 22, 1980
621	CP VIOLATION #621	Gordon B. Thomson	Completed	Aug 29, 1985
622	QUARK #622	Richard Gustafson	Completed	Jun 23, 1980
623	PARTICLE SEARCH #623	Daniel R. Green	Completed	Jun 14, 1982
629	DIRECT PHOTON PRODUCTION #629	Charles A. Nelson, Jr.	Completed	Mar 9, 1981
630	CHARM PARTICLE #630	Jack Sandweiss	Completed	Mar 15, 1982
631	NUC CALIBRATION CROSS SECT #631	Samuel I. Baker	Completed	Jun 1, 1981
632	15-FT NEUTRINO/H2 & NE #632	Douglas R. O. Morrison and Michael W. Peters	Completed	Feb 1, 1988
635	NEUTRINO #635	Luke W. Mo	Approved/Inactive	Feb 1, 1988
636	BEAM DUMP #636	Toshio Kitagaki and Irwin A. Pless	Approved/Inactive	Feb 1, 1988
646	15-FT BEAM DUMP #646	Michael W. Peters	Approved/Inactive	Feb 1, 1988
650	PARTICLE SEARCH #650	Robert C. Webb	Completed	Dec 29, 1980
653	PARTICLE SEARCH #653	Neville W. Reay	Completed	Feb 15, 1988
660	CHANNELING #660	Walter M. Gibson	Completed	Jun 13, 1982
663	LAMBDA POLARIZATION #663	Hans G. E. Kobrak	Completed	Jun 1, 1981
665	TEVATRON MUON #665	Hugh Elliott Montgomery	In Progress	Jul 1, 1987
666	EMULSION EXPOSURE #666	Richard J. Wilkes	Completed	Mar 9, 1981
668	EMULSION/PI- @ 800 #668	Wladyslaw Wolter	Completed	Apr 26, 1985
672A	HADRON JETS #672A	Andrzej Zieminski	In Progress	Feb 15, 1988
673	CHI MESON #673	John W. Cooper	Completed	Apr 14, 1982
683	PHOTOPRODUCTION OF JETS #683	Marjorie B. Corcoran	Set Up in a Year	Feb 15, 1988
687	PHOTOPRODUCTION #687	Joel Butler	In Progress	Jul 1, 1987
690	PARTICLE SEARCH #690	Bruce Knapp	Set Up in a Year	Jul 1, 1986
691	TAGGED PHOTON #691	Michael S. Witherell	Completed	Aug 29, 1985
701	NEUTRINO OSCILLATION #701	Michael H. Shaevitz	Completed	Jun 14, 1982
704	POLARIZED BEAM #704	Akihiko Yokosawa	In Progress	Feb 15, 1988
705	CHI MESON #705	Bradley B. Cox	Completed	Feb 15, 1988
706	DIRECT PHOTON #706	Paul Slattery	In Progress	Jul 1, 1987
710	TOTAL CROSS-SECTION #710	Jay Orear and Roy Rubinstein	In Progress	Mar 31, 1987
711	CONSTITUENT SCATTERING #711	David A. Levinthal	Completed	Feb 15, 1988
713	HIGHLY IONIZING PARTICLES #713	P. Buford Price	In Progress	May 11, 1987
715	SIGMA BETA DECAY #715	Peter S. Cooper	Completed	Feb 14, 1984
720	FREE QUARK SEARCH #720	John P. Schiffer	Completed	Oct 8, 1982
721	CP VIOLATION #721	Jerome L. Rosen	Approved/Inactive	Feb 19, 1988
723	GRAVITATIONAL DETECTOR #723	Adrian Melissinos	Completed	Aug 29, 1985
729	EMULSION/PROTONS @ 1 TEV #729	Atul Gurtu	Completed	Apr 26, 1985
730	EMULSION/SIGMA-MINUS @ 250 #730	Richard J. Wilkes	Completed	Feb 10, 1984
731	CP VIOLATION #731	Bruce D. Winstein	Completed	Feb 15, 1988
733	NEUTRINO INTERACTIONS #733	Raymond L. Brock	Completed	Feb 1, 1988

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APPROVED PROPOSALS *(continued)*

Experiment		*Spokesperson(s)*	*Run Status*	*as of date*
735	PARTICLE SEARCH #735	Laszlo J. Gutay	In Progress	Jul 1, 1987
740	D-0 DETECTOR #740	Paul D. Grannis	Unscheduled	Apr 1, 1984
741	COLLIDER DETECTOR #741	Roy F. Schwitters and Alvin V. Tollestrup	In Progress	Mar 31, 1987
743	CHARM PRODUCTION #743	Stephen Reucroft	Completed	Aug 29, 1985
744	CHARGED INTERACTIONS #744	Frank S. Merritt	Completed	Aug 29, 1985
745	MUON NEUTRINO #745	Toshio Kitagaki	Completed	Feb 1, 1988
747	CHARGED PARTICLES #747	Alan A. Hahn	Completed	Aug 2, 1985
750	MULTIPARTICLE PRODUCTION #750	Ram K. Shivpuri	Completed	Jul 11, 1985
751	EMULSION EXPOSURE @ 1 TEV #751	Piyare L. Jain	Completed	Apr 26, 1985
753	CHANNELING STUDIES #753	James S. Forster	Completed	Jul 5, 1985
754	CHANNELING TESTS #754	Chih-Ree Sun	Unscheduled	Aug 29, 1985
755	BEAUTY & CHARM STUDY #T755	Richard D. Majka and Anna Jean Slaughter	Completed	Feb 15, 1988
756	MAGNETIC MOMENT #756	Kam-Biu Luk	Completed	Feb 15, 1988
758	EMULSION EXPOSURE #758	Mitsuko Kazuno and Hiroshi Shibuya	Completed	Apr 26, 1985
759	EMULSION EXPOSURE #759	Yoshihiro Tsuzuki	Completed	Apr 26, 1985
760	CHARMONIUM STATES #760	Rosanna Cester	Being Installed	Nov 9, 1987
761	HYPERON RADIATIVE DECAY #761	Alexei Vorobyov	Set Up in a Year	Jan 7, 1987
762	EMULSION/PROTONS @ 800 GEV #762	Shoji Dake	Completed	Jul 11, 1985
763	EMULSION/PROTONS @ 800 GEV #763	Takeshi Ogata	Completed	Jul 11, 1985
764	EMULSION EXPOSURE #764	Hirotada Nanjo	Completed	Jul 11, 1985
765	EMULSION/PROTONS @ 800 GEV #765	K. Imaeda	Completed	Jul 11, 1985
766	MR TUNNEL NEUTRONS #T766	Joseph B. McCaslin	Completed	Oct 13, 1985
769	PION & KAON CHARM PROD. #769	Jeffrey A. Appel	Completed	Feb 15, 1988
770	QUAD TRIPLET NEUTRINO #770	Wesley H. Smith	Completed	Feb 1, 1988
771	BEAUTY PRODUCTION #771	Bradley B. Cox	Set Up in a Year	Feb 15, 1988
772	DIMUONS #772	Joel Moss	Completed	Feb 15, 1988
773	ETA00 & ETA+- PHASE DIFF. #773	George D. Gollin	Unscheduled	Jul 1, 1986
774	ELECTRON BEAM DUMP #774	Michael B. Crisler	Set Up in a Year	Feb 15, 1988
775	CDF UPGRADE (LEVEL-3 TRIGGER) #775	Melvyn Jay Shochet and Alvin V. Tollestrup	In Progress	Oct 10, 1988
775A	CDF UPGRADE (SILICON VERTEX) #775A	Melvyn Jay Shochet and Alvin V. Tollestrup	Set Up in a Year	Oct 10, 1988
775B	CDF UPGRADE (MUON SYSTEM) #775B	Melvyn Jay Shochet and Alvin V. Tollestrup	Unscheduled	Jan 30, 1989
776	NUCLEAR CAL. CROSS SECTIONS#776	Samuel I. Baker	Completed	Feb 15, 1988
777	MR TUNNEL NEUTRONS #777	Joseph B. Mccaslin	Completed	May 11, 1987
778	MAGNET APERTURE STUDIES #778	Donald A. Edwards	In Progress	Mar 31, 1987
781	LARGE-X BARYON SPECTROMETER#781	James S. Russ	Unscheduled	Oct 24, 1988
782	MUONS IN 1M B.C. #782	Toshio Kitagaki	Set Up in a Year	Feb 15, 1988
784	BOTTOM AT THE COLLIDER #784	Nigel S. Lockyer	Unscheduled	Jan 30, 1989
789	B-QUARK MESONS & BARYONS #789	Daniel M. Kaplan and Jen-Chieh Peng	Set Up in a Year	Oct 24, 1988
790	CALORIMETER FOR ZEUS #T790	Frank Sciulli	Set Up in a Year	Feb 15, 1988
791	HADROPRODUCTION HEAVY FLAVORS #791	Jeffrey A. Appel and Milind Vasant Purohit	Set Up in a Year	Jun 29, 1988
792	NUCLEAR FRAGMENTS #792	Kjell Aleklett and Lembit Sihver	Completed	Feb 15, 1988
793	EMULSION EXPOSURE 1000 GEV #793	Jere J. Lord	Set Up in a Year	Sep 21, 1988
795	WARM LIQ. CALORIMETRY TEST #T795	Morris Pripstein	Set Up in a Year	Oct 24, 1988
798	SSC DETECTOR TEST #T798	Roger W. Rusack and Priscilla C. Petersen	Unscheduled	Jan 30, 1989
800	MAGNETIC MOMENT #800	Ken Johns and Regina A. Rameika	Set Up in a Year	Oct 5, 1988
802	MUONS IN EMULSION #802	Lali Chatterjee and Dipak Ghosh	Unscheduled	Feb 8, 1989

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PENDING PROPOSALS (13)

Total number of proposals - 804

Experiment		*Spokesperson(s)*
Unconsidered proposals - 12		
667	EMULSION/PI- @ 500 #667	Wladyslaw Wolter
682	POLARIZED BEAM #682	David G. Underwood
688	POLARIZED BEAM #688	W. Rodney Ditzler
699	POLARIZED BEAM #699	Robert W. Stanek
783	TEVATRON BEAUTY FACTORY #783	Neville W. Reay
787	PARTICLE SEARCH #787	Laszlo J. Gutay and William D. Walker
788	NEUTRINO OSCILLATIONS #788	Robert H. Bernstein
794	AXION HELIOSCOPE #794	K. Van Bibber
796	CP VIOLATION #796	Gordon B. Thomson
797	SSC DETECTOR TEST #T797	Dick Gustafson and Rudi Thun
799	CP VIOLATION #799	Yau Wai Wah and Taku Yamanaka
801	PHOTON TOTAL XSECTION ON URANIUM#801	G. L. Bayatian
Not Approved proposals - 1		
719	ELECTRON TARGET FACILITY #719	Wonyong Lee